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CHEMICAL SECTION.*

The Conversion of Amorphous Carbon to Graphite.

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The commercial production of graphite from amorphous carbon having been brought to a successful issue by the Acheson process, the object of the following article is to set forth certain results which have been obtained by various experimenters and have a bearing on the subject. No attempt will be made to review all the work that has been done, but rather to collect in one place some of the more important experiments and speculations which are connected with the relations of amorphous and graphitic carbon.

The earliest systematic experiments on the effect of the high temperature obtainable by electrical means on carbon were those of M. Despretz.† In his experiments, Despretz

* Read by title.

† *Comptes Rendus*, T. XXIX, No. 25, pp. 709–724.

used a battery of 600 Bunsen cells which could be connected up in various ways, according to the nature of the work required, and with these he tried the effect of high temperatures on different varieties of carbon: Retort carbon, anthracite coal, graphite, sugar carbon, carbon obtained by decomposing turpentine in a strongly heated porcelain tube, and finally on diamond. He states, that so far as he could discover, all previous experimenters had come to the conclusion that "carbon is fixed and infusible." Referring to an earlier communication (July 9, 1894) he says: I proved (there) that carbon is volatile like all the bodies called refractory. * * * This volatilization appears in the form of a black cloud which arises from the whole surface of the carbon and deposits, in great part, on the walls of the vessel in which the carbon connecting the two poles of the battery is placed. * * * As I found that carbon dissipated rapidly, both by volatilization and combustion, I tried to diminish the volatilization and eliminate the effect of combustion by working in nitrogen or in a gas that would not support combustion, at a pressure greater than that of the atmosphere."*

The apparatus used by Despretz for these experiments consisted of a cast-iron box, having a capacity of about 10 liters, and provided with a movable cover so that capsules could be placed above and below the material treated with the current or the arc. A vertical rod passed through a leather stuffing box in the cover, and a similar rod passed horizontally through one of the walls of the box. A holder of carbon was attached to each rod. The interior of the apparatus could be observed during the operation through two holes closed with thick glass. Two tubes were also provided, one of which was connected to a manometer, while the other made communication either with an exhaust or compression pump. By means of this apparatus, a current could be passed through a piece of carbon, connecting the carbon holders attached to the vertical and horizontal rods, while in a vacuum or in a gas. In order to experiment with an arc, Despretz had another cover pro-

* *Ibid.*, p. 710.

vided with two rods, at the end of which were attached the carbon holders and between which an arc could be drawn, while with the third rod a piece of carbon could be introduced into the arc. Despretz describes various experiments in which he placed carbon rods between the two electrodes and causing a current to pass through them bent the rods, and makes his first mention of graphite in the following experiment. The carbon rod, 2 centimeters long and 2 millimeters in diameter, was placed between the electrodes, and the current from the 600 cells, arranged in twelve series of fifty elements, was passed through it with the result that the rod bent and broke, the upper part showing an enlargement at the fracture. This enlarged portion resembled "slag" and the ends of the carbon were graphite. In a note on this point Despretz says:

"These experiments are always complex. I describe experiments in which the carbon is bent; but as this result can only be obtained at the highest temperatures, it happens at the same time that in nearly every case a part of the carbon fused and changed into graphite."*

Several other experiments are described in which carbon rods are heated in a similar manner and afterwards found to be graphite. In one of them an electrode, formed of carbon, had "swelled up and was converted into graphite." In some other experiments in which sugar-carbon powder was used for making a close contact with the holders, "certain globules in the powder had been formed by the heat; and in some cases the transformation of the powder into graphite was complete." These phenomena are taken as evidence of fusion.

Despretz next describes how a carbon filament is introduced into the arc, and in one of these experiments with a kind of carbon not indicated the end of the rod swelled up and was converted into graphite. In another experiment a piece of carbon made from turpentine was introduced into the arc with the result that it "shows some points on the heated end which appear to be fused. This end has acquired the properties of graphite, making marks like that sub-

* *Ibid.*, p. 714.

stance, but it does not at once become so brilliant on rubbing, nor is it as soft to the touch."

Experiments are next described in which an arc is made to play on pieces of carbon placed in a sugar-carbon crucible which forms the positive electrode. The most interesting of these experiments, in view of the modern manufacture of graphite, are described as follows:

"Some nearly pure anthracite, treated in the same way, spread out on a crucible like a black glass. . . . A much larger piece of this substance (anthracite) treated in the same manner by the battery, which had been weakened by numerous experiments, exfoliated. The part which received the direct action of the heat became bluish gray in color and was clearly graphite. The part on the edges of the crucible became less hard but was not yet graphite."*

The last experiments we shall notice are described as follows:

"I covered and impregnated some acicular rods of carbon with more fusible materials: silica, alumina and magnesia, in order to see if the presence of more fusible substances made the fusion of the carbon easier in the heat from the battery. The silica, alumina and magnesia were dissipated in the form of vapors and the carbon remained behind retaining its (original) properties.

"I placed an acicular rod of carbon in a clay crucible, filled the latter with well-dried sand, and then passed a current through the carbon which fused and volatilized. I found a sort of very hard fulmineous tube, of which the inside was lined with smoked quartz. The inside diameter was at least ten times that of the carbon."†

As the result of his experiments Despretz concludes that:

"In a vacuum, carbon manifestly vaporizes at the temperature to which it is raised by a battery of 500 to 600 Bunsen cells connected in five or six series. In a gas the vaporization is more gradual but likewise occurs.

"Carbon brought to the temperature which we obtained in our experiments may be bent, welded and fused.

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* *Ibid.*, p. 719.

† *Ibid.*, p. 720.

"Any carbon which is submitted for a long time to a high temperature becomes proportionately softer. Finally it is transformed into graphite."*

In 1870, M. Berthelot published a very interesting article on the allotropic forms of carbon. He refers to the loose way in which the term graphite is employed, as follows:

"Many varieties of amorphous carbon, such as natural plumbago and various artificial carbons, have been associated with graphite. Thus, Berzelius identifies with metallic carbons, coke obtained from the calcination of oil, also charcoal and lampblack after they have been exposed for some time to an intense red heat. In the same way Despretz applies the name graphite to retort and sugar-carbons after they have been heated some time either by the enameling lamp or the electric arc. M. Regnault and M. Caron have designated certain gas-retort carbons with the same name and otherwise conform to Berzelius' opinion.

"If I cite these authorities to specify the sense which has been attached in general, up to the present, to the word graphite, it is because the definition of this substance, whenever it is not crystalline, lacks strictness and gives rise to many ambiguities. For example, the property of marking paper which has often been cited as characteristic of graphite does not belong either to metallic carbons or to certain carbons which I shall class with true graphites; while it is present in lampblack and some other amorphous carbons."†

M. Berthelot then goes on to describe Brodie's discovery of the production of graphitic oxide by the oxidation of graphite with nitric acid and potassium chlorate. As a result of his study of Brodie's process, Berthelot describes a method of distinguishing the various forms of carbon:

"This method consists in oxidizing the carbon at a low temperature and examining the products formed, under these conditions:

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* *Ibid.*, p. 724.

† *Annales de Chimie et de Physique*, p. 392, 3 Serie, Tome xix.

"(1) Diamond is not appreciably oxidized, even by long and repeated treatments, and this is the case whether ordinary or black diamonds are concerned.

"(2) The different varieties of amorphous carbon are completely changed into humic-like acids, yellowish brown in color and soluble in water; the properties of these acids vary, following the carbons which yield them.

"(3) The different varieties of true graphite are changed into corresponding graphitic oxides; the properties of these oxides vary notably with the nature of the graphite from which they are produced; but all are characterized in one way by their insolubility, and above all by their property of decomposing rapidly and with deflagration when heated."*

Berthelot then describes the method he employs for treating the carbon under examination with the oxidizing mixture; calls attention to the fact that the various products of oxidation would lead to a separation of the graphite and amorphous carbon classes into numerous distinct groups, and goes on to say:

"Whatever these more subtle distinctions which require further research may be, the method of analysis which I propose permits a very clear recognition of the three principal groups which comprise the varieties of carbon, viz.: diamond, amorphous carbons and graphites. I propose hereafter to reserve the name graphite exclusively for those carbons which yield a graphitic oxide; this definition will be found to be sufficiently precise and will not give rise to the old ambiguities."†

After describing the method of applying his tests, Berthelot takes up its application to graphites:

"There exist many distinct varieties of graphites; I shall notice especially three, which I have successfully distinguished:

(1) The graphite of natural plumbago.

(2) The graphite of cast-iron.

(3) Electrical graphite, obtained by the transformation

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* *Ibid.*

† *Ibid.*

of different varieties of carbon under the action of the electric arc.

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"A. PLUMBAGO.

(The variety observed by Mr. Brodie).

"The graphitic oxide formed occurs, in the moist state, as micaceous plates of a pale yellow color, insoluble in all solvents (neutral, alkaline or acid) and unaltered by repeated oxidizing reactions. It contains neither chlorine nor nitrogen.

"When it is dried, even at the ordinary temperature, it agglomerates in brown, amorphous, tenaceous plates in which the original structure disappears.

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"B. GRAPHITE FROM CAST-IRON.

"The graphitic oxide from cast-iron occurs in greenish yellow scales, better developed than those of plumbago, and which do not agglomerate in any way during desiccation, but still retain a very characteristic yellow or greenish yellow tint. This characteristic distinguishes them clearly from the oxide of plumbago.

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"C. ELECTRIC GRAPHITE.

"The graphitic oxide of electric graphite has the appearance of a maroon-colored powder, and does not agglomerate sensibly. * * *"*

Next follows an interesting study of the relations between graphitic compounds and organic compounds properly so called, after which there is a discussion of "the actual states of carbon," where the oxidizing action is applied to the usual varieties of carbon, to carbon that has been treated in various ways, and, finally, to carbon prepared by the decomposition of its compounds with numerous other bodies, such as hydrogen, oxygen, metals, etc. Passing over the experiments on the "usual varieties," we come to the consideration of the effects of heat:

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* *Ibid.*

"By the action of heat alone, that is to say, by calcining graphites and various amorphous carbons at a white heat in an atmosphere of hydrogen, I never was successful in passing from one group to another; only amorphous carbons appeared to show some increase in cohesion. * * *

"Chlorine, at a white heat, does not change charcoal into graphite nor graphite into amorphous carbon; it is known, besides, that chlorine does not attack free carbon. Iodine at a red heat does not change coke into graphite; on the other hand, iodine brings about this transformation by acting on nascent carbon, as will be shown later.

"The action of oxygen is more complicated. It, in fact, gives rise simultaneously to an extreme elevation of temperature and to a formation of dioxide and monoxide of carbon. Carbon submitted to this double action may be studied by burning a retort-carbon rod, previously heated to redness, in a stream of oxygen. When the end of the rod is fully incandescent it is rapidly extinguised by plunging it in cold water. Then the extreme point of the pencil is removed, care being taken to confine oneself as far as possible to that portion which has been most strongly heated. The carbon thus treated is no longer composed exclusively of amorphous carbon, but contains a small quantity of graphite formed by the double action of heat and oxidation.

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"No action is more worthy of interest than that of electricity. I have examined, by the new method of analysis, the carbon poles used in the electric light. It is known that under this action the carbon is vaporized and passes from the positive pole, which becomes continually smaller, to the negative pole, which becomes covered with a spongy mass. I oxidized the carbon powder collected from a large number of carbons that had been used in producing electric light and obtained great quantities of graphitic oxide. This graphitic oxide, and, consequently, electric graphite, are not identical with those of cast-iron or those of plumbago.

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"The formation of electric graphite does not occur indifferently at the two poles. The negative poles, thickened by

the transport of the carbon, alone yielded a large quantity of graphitic oxide; while the corresponding positive poles, attenuated by the action, only contained traces; moreover, these were probably due to the necessarily imperfect separation of the carbon which deposited on the poles during the action of the electric light.

"Nevertheless, the transformation into graphite does not necessitate the preliminary volatilization of the carbon. In fact, the capsules of sugar carbon, softened by the arc from a battery of 600 elements, were found to be, in great part, changed into graphite at the negative pole."*

The capsules referred to were those used by Despretz in his experiments.

Omitting details, the results of the next experiments are as follows:

Decomposition of hydrocarbons by heat alone yields amorphous carbon.

Decomposition of methane by the electric spark yields amorphous carbon with a trace of graphite.

Decomposition of methane by chlorine yields amorphous carbon..

Decomposition of benzene, naphthalene and other hydrocarbons at 280°, as iodine and hydrochloric acid, yields amorphous carbon; but at higher temperatures decompositions with these reagents can be effected with the production of considerable quantities of graphite which appear to be analogous to the electric variety.

Lampblack, produced by the combined action of heat and oxidation, yields traces of graphite.

Decomposition by heat of chloride of carbon yields graphite in considerable quantities, and the same results are obtained by the decomposition of carbon bisulphide, though the graphite obtained from the latter will not mark paper.

Cyanogen, decomposed by the electric spark, yields amorphous carbon with traces of graphite.

Sodium carbonate, decomposed by heating with phosphorus, yields amorphous carbon and a little graphite.

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* *Ibid.*

Red-hot sodium reacting with sodium carbonate yields a small quantity of carbon composed, in great part, of graphite. The experiments with carbide of boron and certain metallic carbides are of such interest, in view of later work, that they will be quoted in full.

"*Carbide of Boron.*—It is known that M. H. Saint-Claire Deville has designated by the name of adamantine boron a variety of crystalline boron, which is hard and brilliant and contains a certain percentage of carbon. It is easy to separate the carbon by treating the boron with a current of dry chlorine at a red heat. I have effected this separation at two very different temperatures, namely: at a temperature lower than that of the softening of glass, and at a temperature near that of the fusion of porcelain. In both cases the carbon was composed of graphite, transformable into graphitic oxide and not containing the faintest trace of diamond. The only difference between the two experiments was, that the graphite prepared at a dull red heat was amorphous, while the graphite prepared at a white heat was crystallized in the hexagonal form well known to mineralogists.

"The latter carbon was deposited, in part, at some distance from the place where the boron had been originally placed—a phenomenon of transport which is probably due to the formation of a double chloride of carbon and boron. Some of the crystals, on account of an unequal development of their angles, showed in a striking manner under the microscope the appearance of truncated octahedra, calculated to lead a prejudiced mind into error. Observed in place, that is to say, on the surfaces where they were deposited, these crystals presented a singular luster and brightness which is never looked for in a substance like graphite. Nevertheless, the form of these crystals, when examined, as well as their transformation into graphitic oxide, leaves no room for any doubt.

"*Carbide of Iron.*—It is known that graphite separates from cast-iron in crystalline plates. I examined likewise the combined carbon in iron. It was separated from white cast-iron by two distinct processes, namely: by the action

of chlorine at a dull red heat and by the action of mercuric chloride (Boussingault's process).

"The carbon obtained in this way is, in both cases, composed of a mixture of amorphous carbon (predominant) with a little graphite. It would be interesting to know if there exists some relation between the various properties of cast-irons and steels and the amorphous or graphitic nature of the carbon which is found there in the combined state.

"*Carbon from Manganese.*—M. Caron was kind enough to give me a specimen of carbon which he had separated from some metallic manganese prepared by him. This specimen was composed entirely of amorphous carbon.

"Recapitulating, the carbon separated from the carbides of hydrogen by the action of heat does not contain a trace of graphite; while the carbon separated from sulphide and chloride of carbon by the action of heat or from boron by the action of chlorine contains a considerable quantity of graphite. The carbon separated from carbon dioxide (combined with soda) cannot be obtained under conditions as simple or as free from secondary complications; with this reservation, we have seen that the carbon separated either by means of phosphorous or sodium contains a certain proportion of graphite. It is the same with the carbon separated from organic compounds by incomplete combustion, that is to say, under the combined action of heat and oxygen.

"I believe it results from these observations that carbon, in separating from hydrogenous compounds, assumes by preference the state of amorphous carbon; while carbon separating from its combinations with chlorine, sulphur, boron and perhaps oxygen under the action of heat, shows a certain tendency to assume the state of graphitic carbon. I have already pointed out an analogous contrast between the several states of sulphur separated from its combinations. Finally let us add, that graphitic carbons and amorphous carbons seem to represent, not the several states of carbon itself, such as would exist in its compounds, but certain corresponding polymeric states of that element.

"All these comparisons, I repeat, are of the same order

as those which result from the study of the manifold states of sulphur and phosphorus in their combinations. But there exist here certain analogies and certain dissimilarities on which it is important to insist.

"In fact, sulphur in its various states has the same specific heat, and this is also the case with ordinary and red phosphorus. The variety of these isomeric states of a given element does not surpass that which exists between the isomeric states of a given liquid hydrocarbon such as the states of the carbide $C_{20}H_{16}$—terebenthene, citrene, terebene. Neither does it surpass that which exists between the various polymers, liquid or solid, of a given carbide in different states of condensation, such as $C_{20}H_{16}$. In fact, all these carbides possess nearly the same specific heat.

"Such also are the differences which exist between the several graphites, whether the several graphites represent the manifold isomeric states of a given, equally condensed carbon, or whether they correspond to the several condensations of that element. Similar remarks apply in general to amorphous carbons. Here, then, we have examples of a certain species of isomerism and polymerism which does not change the specific heat appreciably.

"On the other hand, the comparative study of amorphous carbons, graphites and diamond reveals to us another mode of the condensation of matter more profound than that of ordinary polymerism, and communicating to the specific heat variations of the same order as those observed in passing from one elementary body to another."*

M. Moissan made a very careful research on the different varieties of carbon—amorphous, graphite and diamond—finally producing diamonds in his electric furnace.† His experiments show that "it is very difficult to obtain pure amorphous carbon."

"When carbon is obtained at ordinary temperatures and pressures, it appears in the form of an impalpable maroon-colored powder. It is very light, is not hard and is easily oxidized by nitric or chromic acid.

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* *Ibid.*

† "Le Four Electrique," Paris, 1897, pages 53-203.

"This carbon always contains a certain amount of some elementary bodies—hydrogen, iodine, lead, zinc, etc.—with which it is associated during the reaction. To remove these impurities the carbon must be heated, that is to say, it must be polymerized."*

In his study of graphite Moissan examined a number of natural graphites, then proceeded to produce graphites in the electric furnace and describes three methods of performing that operation, which are briefly as follows:

(1) Amorphous carbon is heated to a very high temperature in the electric furnace, the conversion to graphite being effected by "simple elevation of temperature."

(2) An excess of carbon is dissolved in a metal or metalloid at a high temperature. The solvent is then allowed to cool down and the excess of carbon separates in the form of graphite.

(3) Carbon is dissolved or combined with another element and then thrown out as graphite by the introduction of some other body.

While lack of space forbids a description of all Moissan's experiments, typical examples illustrating the different methods may be noted.

(1) "Sugar carbon, purified by chlorine and placed in a closed crucible, was heated for ten minutes by an arc of 350 amperes and 70 volts. The appearance of the carbon is sensibly the same as before the experiment; however, its color has become grayer. * * * At the third treatment with the oxidizing mixture (potassium chlorate and nitric acid) it was transformed into pale yellow graphitic oxide.†

(2) "When aluminum is heated for five or six minutes in the electric furnace (350 amperes and 70 volts) in the presence of sugar carbon or simply in a carbon crucible, the metal carburizes and on cooling a residue, showing a yellow crystalline fracture and containing aluminum carbide, C_3Al_4, is obtained. If it is heated for ten or twelve minutes, the aluminum carbide volatilizes partially and there remains a

* *Ibid.*, p. 69.
† *Ibid.*, p. 86.

brittle, porous, gray substance covered with crystals of graphite. The latter is separated by treatment with hydrochloric acid, then purified by sulphuric and hydrofluoric acids. Finally it appears in groups of very brilliant little crystals, sometimes showing some black filaments. Its density is 2·11. On the first treatment with the oxidizing mixture the graphite swells up, and on the second the smallest fragments are completely transformed into graphitic oxide."*

(3) "We started out with a gray cast-iron from Saint-Chamond, which contained 3·18 per cent. total carbon and 0·5 per cent. scoriæ. (In the analysis of iron, the mixture of the different varieties of carbon is separated by chlorine or mercuric chloride. The residue is burnt in oxygen and we give the name scoriæ to the ash which remains.)

"Ten grams of the cast-iron were placed in a porcelain boat lined with 2·3 grams of boron. The whole was heated strongly in a porcelain tube filled with dry hydrogen and placed in a reverberatory furnace. After the experiment a well fused residue, covered with a black layer composed entirely of graphite, was found in the boat."†

Moissan experimented with several elements in the production of graphite by the method of different solubilities at high and low temperatures, and the experiment with silicon is of especial interest, in view of the history of the Acheson method of producing graphite.

"When fused silicon is heated in a blast furnace it dissolves carbon, which it finally gives up in the form of graphite—clear crystalline plates of a brilliant black color and yielding a yellow graphitic oxide.

"At the temperature of the electric furnace silicon no longer yields graphite; it produces crystalline carbide of silicon."‡

Moissan's "Study of Carbon Vapor" is also worthy of note in this connection.

"Hitherto the formation of the vapor of carbon has not

* *Ibid.*, p. 88.
† *Ibid.*, p. 93.
‡ *Ibid.*, p. 92.

been demonstrated except in the electric arc, either by spectral analysis or by M. Berthelot's beautiful synthesis of acetylene.

"The existence of this vaporization outside the arc may be demonstrated in the following fashion: If a carbon tube, having an interior diameter of about 2 centimeters, is placed in an electric furnace made of lime, and heated by a powerful arc of 2,000 amperes and 80 volts, the interior of the tube is seen to be rapidly filled with a very light, black lining produced by the condensation of the carbon vapor.

"The carbon vapor may be made visible by placing a boat containing crystalline silicon in the middle of the strongly heated carbon tube. The silicon is then seen to fuse, to enter into ebullition, and as its vapor rises it meets the carbon vapor which descends from the upper part of the tube under the heat of the arc. There is produced between the boat and the tube a network of fine needles of silicon carbide. This crystalline and transparent compound is formed by the direct union of the two vapors."*

Certain natural graphites have a peculiar property of swelling up when treated with nitric acid and then heated to a temperature of about 200.° Moissan investigated this phenomenon and found that he could produce these swelling graphites in the electric furnace. He also made some experiments which seem to show that the swelling is caused by a rapid evolution of gas contained in the graphite.

Moissan's conclusions are as follows:

"According to M. Berthelot's definition we shall give the name graphite to the usually crystalline variety of carbon of which the density is about 2·2 and which yields a clearly characteristic graphitic oxide on treatment with the oxidizing mixture of potassium chlorate and nitric acid.

"Graphites are found on the surface of the earth and in certain meteorites. They may be divided, as M. Luzi recommends, into swelling and non-swelling graphites.

"The graphites obtained in the electric furnace by simple elevation of temperature are not swelling graphites.

* *Ibid.*, p. 159.

"On the other hand, all those which are obtained in a liquid metal at a high temperature, either by difference in solubility or by simple chemical reaction, have the property of swelling readily. This swelling graphite is very easily prepared in the electrical furnace by boiling platinum in a carbon crucible.

"The swelling of this variety of graphite should be attributed to a rapid evolution of gas.

"Artificial graphites may be amorphous or crystalline. Their density varies between 2 and 2·25. Their temperature of combustion in oxygen is about 660°.

"When they are pure they contain no hydrogen.

"A graphite obtained in the electric furnace, treated with no reagent and previously heated in a vacuum does not yield any water when burned in oxygen. On the other hand, ordinary cast-iron, treated with dilute acids, yields hydrogenous and oxygenous compounds which are indestructible at a red heat.

"When a graphite is prepared in the electric furnace its resistance to oxidation is proportional to the elevation of the temperature to which it has been brought.

"A graphite that is easily attacked, like Ceylon graphite, may be made more difficult of attack by heating strongly. This fact establishes the existence of many varieties of graphite analogous to the different varieties of amorphous carbons."*

In 1893 Girard and Street, in a lecture before the Société Internationale des Électriciens, describe a furnace which may be used for the conversion of carbon into graphite. The method consists in causing an arc or series of arcs to play over the surface of the carbon that is to be converted into graphite. It is stated that 85 per cent. of the carbon is transformed into graphite by this process.†

In 1891 Mr. E. G. Acheson, while attempting to obtain a hard crystalline form of carbon, discovered the new compound silicon carbide, now well known as an abrasive under

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* *Ibid.*, p. 110, 111.

† Becker: *Manuel d'Electro-Chimie*, p. 449-458.

the name carborundum. Recognizing at once the valuable properties of this new compound, Acheson rapidly developed its manufacture and designed a new form of furnace for this purpose. The furnace was a brick box with an open top and carried carbon terminals at either end. In operating the furnace it was filled with a mixture of sand and coke, and the terminals electrically connected by means of a granular carbon core through which the current passed, heating it to such a high temperature that the carbon in the surrounding mixture reduced the silica and formed silicon carbide. After operating these furnaces Acheson usually found a layer of brilliant graphite lying between the core and the crystalline carborundum, and examination showed that this was formed by the decomposition of the silicon carbide. The temperature of the core, other things being equal, is a function of its sectional area, and hence if this happens to be somewhat smaller than usual the temperature will be proportionately higher and the silicon carbide in immediate contact with the core will be decomposed, the silicon being vaporized and the carbon left behind as graphite. The granular carbon, usually coke, composing the core of the furnace, also showed change, for the grains became softer and would mark paper like a pencil, left a brilliant polished surface on rubbing, were good conductors of heat and electricity and were almost chemically pure, containing only about 0·2 per cent. of ash. Sometimes petroleum coke was used to form a core, but that material did not yield a carbon, having all the clear characteristics of graphite. The granular carbon that had already been used as a core in a carborundum furnace was known as "old core" and was of much value, owing to its low electrical resistance, for if it was used to form the core of the next furnace the latter could be brought to its working temperature in a very short time. Acheson found that no matter how often this granular carbon was used as a core no further appreciable change in its properties occurred after the first time. Careful examination of the grains of the old core showed Acheson that these were by no means homogeneous, some being dull black in color and nearly as hard as the

original coke grains, while others had a brilliant metallic luster and could be cut with a knife like a piece of cheese. Further observation showed that the relative quantities of the dull, hard grains and the brilliant soft variety depended upon the coke used in making the core, and that the results obtained with different cokes depended upon the ash content. Combining these observations with those on the decomposition of silicon carbide, Acheson concluded that a general method for the production of graphite might be found in the formation and decomposition of carbides. The experiments undertaken to test this theory resulted in a patent on the "Manufacture of Graphite," in which Mr. Acheson says:

"I have also discovered, that in order to produce pure graphite from carbonaceous materials there is an indirect conversion, and that the act of formation of the graphite is more in the nature of an act of dissociation of the carbon from its combination with other materials than a conversion of the ordinary carbon into graphite, and that as a preliminary step the carbon has to be combined chemically with some other material. Thus I have found that if the carbonaceous material or carbon used in the process contains a considerable proportion of mineral matter, or if it is mixed with a certain proportion of oxide or oxides such as silica, clay, alumina, magnesia, lime or oxide of iron, the yield of graphite is enormously increased and the product is more satisfactory." *

An experiment which demonstrated the effect of carbide formation very clearly was the following: Two carbon rods, one composed of very pure lampblack carbon and containing less than 0·2 per cent. of ash, the other made of petroleum coke carbon which had been intimately mixed with a certain amount of ferric oxide, were heated side by side in an electric furnace. At the end of the experiment the rod that had contained the iron was found to be graphitic; could be easily cut with a knife, took a beautiful metallic luster on rubbing and would mark paper like an ordinary pencil. The pure

* U. S. Patent, 568,323, September 29, 1896.

carbon rod showed little change, was dull black in color, nearly as hard as before heating, and would not leave a mark on paper. One end of this carbon rod, however, was clearly graphite from the fact that it had been exposed to the action of vapors of carbide-forming elements. These vapors had even penetrated to a certain depth in the carbon rod, and in so far as this had occurred the rod showed a brilliant graphitic appearance, was soft, etc. This experiment will be referred to again in discussing M. Berthelot's researches.

It might be supposed that the production of graphite in the manner described above would necessitate the mixture of carbon and carbide-forming material in proportions such that the carbon present would be completely satisfied. Acheson's experiments showed, however, that the desired result could be obtained by a very much smaller percentage of the carbide-forming element, which apparently has the power of acting on successive quantities of carbon.

Having finished his preliminary experiments, Mr. Acheson formed a company for working his process of making graphite, and began to produce it on a commercial scale. The furnaces used in the Acheson process for making graphite electrodes and graphite commercially are very similar in outward appearance and magnitude to those used in Acheson's process for making carborundum. They are built of brick, in the form of a long, narrow trough, lined with some suitable refractory material. In making graphite electrodes the latter are manufactured of petroleum coke and pitch, like an ordinary carbon, such as is used in arc lights; but a certain amount of some carbide-forming material, such as silica or iron oxide, is introduced. The electrodes are baked in the usual way and are then ready for graphitization. To perform this work they are placed in a furnace and heated to a temperature above that of the volatilization of such bodies as iron, aluminum and silicon. That the temperature used in the Acheson furnaces is well above this point may easily be demonstrated, as the bodies above named are condensed in the form of their oxides outside the furnace.

In manufacturing graphite for other purposes, such as crucibles, paint, stove polish, etc., anthracite coal is usually employed. Having found a process for making graphite, Acheson next set to work to find a natural carbonaceous substance which would yield a graphite suitable for commercial purposes. He experimented with a great many materials, and finally discovered that anthracite coal gave the most satisfactory results. The furnace is filled with anthracite coal, through the center of which runs a core composed of carbon rods which connect the terminals of the furnace electrically. When cold, anthracite coal is a very poor conductor of electricity, hence the necessity for the core, which acts as a conductor and heats the surrounding anthracite when the furnace is started. Finally, the whole mass is raised to a very high temperature and converted into graphite.

Careful study of the products of the Acheson process has shown that, according to Berthelot's definition, the conversion of the amorphous carbon into graphite is complete, for the oxidizing mixture of nitric acid and potassium chlorate does not produce the least trace of the brown soluble body, characteristic of amorphous carbon, but yields only graphitic oxide.*

The density is increased considerably by the conversion of amorphous carbon into graphite:

Mean value of densities of six electrodes before graphitizing . .	1·90
Mean value of densities of the same after graphitizing	2·19

The electrical conductivity of the carbon is greatly increased by conversion into graphite, as is shown by the following results obtained by Mr. P. M. Lincoln, Resident Electrical Engineer of the Niagara Falls Power Company:

Resistance of 1 cubic inch of amorphous carbon electrode	0·00124 ohm.
Resistance of 1 cubic inch of graphite electrode . . .	0·000320 ohm.

The purity of the graphitized carbon is greater than that of the amorphous from which it is made, for a greater or

* *Journal of the Society of Chemical Industry*, May, 1901.

less quantity of the contained impurities is volatilized, the final purity depending on the temperature to which the carbon has been raised and the time expended in heating. A specimen of anthracite coal was analyzed and found to contain 5·783 per cent. of ash. After prolonged heating and conversion into graphite the latter was found to contain only 0·033 per cent. of ash. Dr. Foerster, of the Dresden Technische Hochschule, has shown the remarkable resistance of Acheson graphite to disintegration in certain electrolytes.*

In some early experiments on the reduction of oxides by carbons, Dr. W. Borchers used an electric furnace which had for terminals two relatively large carbons connected to each other by a carbon rod of much smaller diameter. The small rod was highly heated by the passage of the current and was surrounded with the mixture of oxide and carbon on which he wished to make experiments. Like Despretz, Borchers found that when, in manipulating the terminal carbons, he applied pressure to the ends of the small highly heated rod it bent, and that on cooling it assumed a hard crystalline state. He found that the greater the impurities the lower the temperature at which the rods bent and the harder they were on cooling; also that substances which form alloys or decomposable compounds with carbon further its crystallization. Finally he describes an apparatus with which he believes valuable results might be obtained along the lines of his experiments.†

We may notice briefly a patent granted to Mr. H. Y. Castner in 1896 for an "Anode for Electrolytic Processes," in which is described a process for heating carbon electrodes by means of electricity to a very high temperature, with the result that a "graphite-like form of carbon is produced." It might be supposed that Castner's electrode was an anticipation of the Acheson graphite electrode were it not that Castner states that after treatment the electrode "will be found to be of decreased density." The Acheson

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* *Zeitschrift für angewandte Chemie*, June 25, 1901.

† *Zeitschrift für Elektrochemie*, March 20, 1897.

graphite electrode, being actually converted into graphite, has a considerably higher density than the amorphous carbon of which it is made. In describing his process Castner also states that the temperature produced is such that "the carbon will give off the more inflammable material it contains." We may conclude, therefore, that Castner's process was nothing more than the electrical baking of carbon anodes.*

September 2, 1901, a German Patent granted to John Rudolphs and Johannes Härden, of Stockholm, was published. The specification for this patent describes a "process of obtaining graphite from carbon by means of electrical current." Attention is called to the fact that heretofore carbon has been converted into graphite by heating alone, care being taken to avoid oxidation during the process. The inventors propose to graphitize carbon by the simultaneous action of a high tension alternating current of high frequency, and a heating current of the usual kind. It is claimed that "the conversion of the carbon to graphite proceeds far more rapidly than by electrical heating alone; furthermore, experiments have shown that by means of this invention it is possible to graphitize much larger carbon pieces than is possible by known methods. This advantage may rest upon the fact that the high-tension alternating currents of high frequency produce very rapid ether-vibrations, which seem capable of favorably influencing the molecular alterations of the carbon pieces undergoing treatment.

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"With the object of preventing the combustion of the carbon pieces to be treated, it is advisable to conduct the operation in an exhausted chamber or in the presence of inert gases in order to prevent, according to known methods, access of air to the glowing carbon."

Finally the following claim is made in the patent:

"Process of obtaining graphite from carbon by means of electric currents, characterized by the fact that a low-ten-

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* U. S. Patent 572,472, December, 1896.

sion heating current either in the form of a direct current or of an alternating current of low frequency (about 25 to 100 alternations per second), and a high-tension alternating current of high frequency (at least 50,000 alternations per second), are permitted to act simultaneously upon the carbon." *

This review of the more important work done on the production of graphite makes it clear that the various experimenters are by no means in agreement as regards the results they have obtained. Despretz in his experiments was endeavoring to show that carbon could be fused, welded and volatilized and thought he had done so. Moissan, however, in his experiments never found any sign of fusion, and concludes that vaporization occurs without previous fusion. In some of his experiments, at least, Despretz probably mistook the formation of fusible carbides for fusion of carbon. If a carbon rod is thoroughly impregnated with iron oxide and then heated electrically to a temperature somewhat below that of the volatilization of iron it will be found to be covered with little fused globules having a brilliant black metallic luster, and leaving a mark on paper like graphite. Examination of these globules proves that they are composed of iron intimately mixed with graphite, which has been formed by the method of "different solubilities" and not by fusion of the carbon as Despretz supposed. It is difficult to offer any explanation of Despretz's experiment with the anthracite which "spread out on the crucible like a piece of black glass." In the commercial manufacture of graphite, hundreds of tons of anthracite have been completely converted into graphite, but no phenomenon like this has ever been observed. The ash in anthracite coal is usually very evenly distributed, as may be seen by burning a lump of the coal; but it is not uncommon to find a very large excess of ash in part of a specimen that otherwise contains a low percentage. It is possible that the anthracite used by Despretz contained very little ash as a whole, but that the particular piece taken in this experiment was

* German Patent No. 123,692, Class 12i, February 28, 1900.

very impure. Equally remarkable is the experiment where the carbon rods were impregnated with silica which was volatilized without producing any change in the carbon. As Despretz was looking for the fusion of carbon he may have overlooked other changes in its properties. Despretz's conclusion that any carbon becomes proportionately softer as it is heated for a long time to a high temperature is incorrect. Take, for example, the ordinary manufactured carbon, the hardness of which is increased by prolonged baking at a very high temperature, or take some forms of anthracite coal, which may be so greatly hardened by heating for some time to a high temperature out of contact with air that they will readily scratch glass.

Berthelot's researches bring out very clearly the peculiar properties of the different forms of carbon and the relations existing between the different states of the same element, thus lessening to a great extent the apparent incongruity of the results obtained in the work of different experimenters. Some of these incongruities are due to the ambiguity in the use of the word graphite. Berthelot's definition of graphite as that form of carbon which on oxidation at low temperatures yields graphitic oxide is perfectly satisfactory from the chemical point of view, but it is not always satisfactory in practice; for example, as Berthelot himself points out, some forms of carbon which will come under his definition will not mark paper. Reference has already been made to one of Acheson's experiments in which two carbon rods, one containing metallic oxide and the other being pure, were heated side by side in an electric furnace. Subsequent examination showed that both carbons could be converted into graphitic oxide, and hence that they both were graphites according to Berthelot's definition. Nevertheless, the carbon which had originally contained practically no metallic impurities had none of those properties which are ordinarily recognized as characteristic of graphite. Incidentally, it is worth noting that an experiment on the relative incombustibility of the carbons showed that the carbon which had originally been pure oxidized nearly 100 per cent. more rapidly than the other carbon. The conclusion to be drawn

from a comparison of Berthelot's and Acheson's researches seems to be that while all true graphites yield graphitic oxide, all bodies yielding that compound are not necessarily graphites suitable for practical purposes. In view of the fact that various kinds of hard and soft graphites produced by artificial means are now being put on the market, and that varieties of amorphous carbon (notably retort carbon) are also sold under the name of graphite, it would seem to be advisable to revise the nomenclature of carbons, reducing it to a more rational and practical form that will be free from all such ambiguities.

The experiments on the separation of carbon from the carbides of boron, iron and manganese are particularly interesting, showing, as they do, that in order to produce graphite the method of decomposing the carbides is by no means indifferent. The boron carbide alone yielded graphite by Berthelot's method of separation, while Acheson's method of decomposing the same carbides produced graphite in every case.

So far as Berthelot's experiments went amorphous carbon is not converted into graphite by simple elevation of temperature. In order to bring about this transformation the presence of oxygen, or some other body, seems to be necessary, or an electrical influence must be present. In the case of arc-light carbons special stress is laid on the fact that graphite is produced to an appreciable amount on the negative pole only, and the examination of Despretz's capsules showed that they were converted into graphite "at the negative pole."

The most interesting of Moissan's methods of transforming amorphous carbon into graphite, as compared with the commercial method, is the conversion by "simple elevation of temperature." While his investigations show clearly that heat has a most distinct effect in bringing about the polymerization of both carbon and graphite, yet, in view of Acheson's work on the remarkable part played by various carbide-forming substances in effecting the transformation of amorphous carbon into graphite, none of Moissan's experiments is rigidly conclusive in demonstrating that the

change is effected solely by elevation of temperature. Even placing the specimen of carbon in a covered carbon crucible does not necessarily protect it from the action of the metallic vapors which must invariably have been present in Moissan's furnace, since at high temperatures the densest carbons are very porous. Moissan refers to this porosity in the description of his tubular electric furnace,* and in certain experiments made at the works of the Acheson Graphite Company, very dense carbons at high temperatures were found to be astonishingly porous to metallic vapors.

The experiment cited as proving the vaporization of carbon outside the arc is difficult to understand when taken in connection with Acheson's production of graphite by the decomposition of silicon carbide. In Moissan's experiment, silicon was boiled and its vapor combined with "the carbon which descends from the upper part of the tube," and formed silicon carbide. Acheson placed a mass of silicon carbide in an electric furnace and heated it to a high temperature, so high that the carbide was decomposed, the silicon being completely vaporized, while the carbon formed a graphite skeleton of the crystals, the angles of which were perfectly clear and sharp, showing that there had not been the smallest vaporization of the carbon. In the description of Moissan's experiment we are not told whether an inert gas was passed through the tube or that any special precautions were taken to avoid all possibility of the entrance of air during the heating. If this were not done, carbon monoxide gas would be formed, and in contact with a relatively large mass of silicon vapor would probably be reduced with the formation of silicon carbide crystals and silica in the form of vapor. The silica vapor in contact with a large excess of carbon (the walls of the tube and the carbon boat) would in turn be reduced, silicon carbide and carbon monoxide being formed. This explanation is possible, in view of the fact that at very high temperatures the direction of the reducing action seems to depend largely on the relative masses of the reacting bodies. As for the light black lining

* "Le Four Electrique," p. 24.

of the tube "produced by condensation of the carbon vapor," that could be produced by the disintegrating action of the oxygen of the air playing upon the walls of the tube. Some such action seems more probable than the supposition of vaporization, since the latter would require the condition that there should be no drop in temperature between the outside of the tube, on which the arc is playing, and the inside.

Here attention must be called to an interesting article by Clinton Paul Townsend, in which he discusses the work of the various experimenters, and finally suggests that their results may be reconciled by the hypothesis that "the preliminary ionization of the carbon is essential to the production of graphite. For it will be noted that when Moissan speaks of 'elevation of temperature' he means the heat of the electric arc, whereas Acheson and Borchers refer to the heat developed in a carbon resistance. In the former case conditions favorable to the ionization of the carbon are present, while in the latter such effects are excluded. * * *

"Other of the observations before referred to tend to confirm the view that the production of graphite is due to more than the simple heat-effect of the current. Berthelot's supposition that the mixture of the two forms of carbon, which results from the passage of an electric discharge through hydrocarbons and cyanogen, is due to the joint action of heat and electricity, appears eminently probable. * * * If we re-examine the work of Despretz we find that whenever the arc was used the transformation to graphite was readily accomplished, even though the ash-content of the carbon were only one part in 7,000; but when the carbon, as a filament, was directly included in the circuit, the results are less positive, and the production of graphite seems to follow either the presence of a large admixture of ash, or the rupture of the filament."*

The process described by Rudolphs and Härden in their patent is interesting, but we have not been able to find any more details of the method than those given in the patent.

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* *Electrical World and Engineer*, April 6, 1901.

The results obtained by Borchers in his experiments tend to show that carbide-forming substances "further the crystallization of carbon," and so far confirm Acheson's observations on the important part played by these bodies in passing from one allotropic form of carbon to another; but they do not form good ground for the claim of priority advanced by Borchers,* for they were published long after Acheson's results were made known in his patents.

It may be well to note here an extraordinary claim put forward by Dr. Otto Mühlhaeuser† that he is the original discoverer of the fact that graphite is produced by the decomposition of silicon carbide. Mühlhaeuser was employed for a few months as chemist of the Carborundum Company, but the records show that Mr. Acheson's application for the carborundum patent was made before Mühlhaeuser even arrived in America, and the specifications show that Mr. Acheson was then familiar with the production of graphite in this way.‡

TO PREVENT THE FREEZING OF GAS-PIPES.

A simple but effective device for preventing the freezing of gas-pipes is described in the *Illustrirte Zeitung für Blechindustrie*. It consists merely in the insertion of a wider piece of pipe just where the conduit issues from the ground or wall. For a conduit of a diameter from ⅜ to ½ of an inch a length of from 20 centimeters to 30 centimeters of a pipe 1 inch in diameter suffices. The deposition of the water particles contained in the gas, which on leaving the works have a temperature of about 50° F., naturally takes place just where the gas is subjected to the most abrupt change of temperature, *i.e.*, on its issue from the ground. If the external temperature is sufficiently low, the deposited water immediately congeals and clogs the conduit. As soon as the gas has acquired the temperature of the conduit the deposition of water and congealing cease, and this is said to be the case a short distance beyond the first cooling point. Therefore, there should be no congealing beyond the inserted wider piece, and this piece is wide enough to accommodate a thick ice-crust and to still leave a free passage for the gas. As a matter of fact, the principle of this new method is already employed in street lamps, and with success.—*Scientific American.*

* *Zeitschrift für Elektrochemie*, September, 1899.
The Mineral Industry, vol. 8, p. 678.
† *Chemiker Zeitung*, No. 31, vol. 26.
‡ U. S. Patent 492,767, February 28, 1893.

CHEMICAL SECTION.

Stated Meeting, held Thursday, February 27, 1902.

The Analytical Methods for Carbohydrates as Applied to Foods and Feeding Stuffs.

By William H. Krug,
U. S. Department of Agriculture.

The analysis of a food or a feeding stuff has for its object either a determination of the nutritive value of the material or the detection of an adulteration. Of these the latter is probably the most important, since it is of direct interest to the public at large and is intimately connected with the general health and moral status of a people. The adulteration of food may be broadly classified as that which is merely a financial fraud and consists of the partial or total substitution of an article innocuous in itself but sufficiently lower in price to induce the sophistication, and that which by its use becomes a direct menace to the health of the purchaser. Both forms of adulteration are extensively practised, and it is a natural sequence that food-chemistry has rapidly become a special branch and has experienced a remarkable development in recent years. The results of the studies of many able investigators are manifested in the strict food laws adopted by almost all European countries and in the analytical methods which are to-day used and which, while in some instances not absolutely reliable, are still found to be generally satisfactory, and are accepted by the courts in cases of prosecution for adulteration.

Before entering into a discussion of the application of the results obtained in the determination of the carbohydrates in foods it may be well to say a few words concerning the general analytical methods. With few exceptions, the methods employed for the determination of the water-soluble carbohydrates are either physical (polariscopic methods) or depend upon the reducing power of the sugar when brought

in contact with a boiling alkaline copper solution. The polariscopic methods are based on the property possessed by all sugars to a greater or less degree of rotating a polarized ray of light, and a number of instruments have been devised to measure the degree of rotation. The one now most commonly used has been designed by Schmidt and Haensch, and is constructed in such a manner that a solution of pure sucrose containing 26·048 grams in 100 Mohr's cubic centimeters when observed in a 200 millimeter tube at 17·5° C. will read exactly 100. This weight corresponds to 25·9872 grams in 100 true cubic centimeters, and the International Commission for uniform methods of sugar analysis at the Paris meeting in 1900 decided to adopt 26 grams in 100 true cubic centimeters at 20° as the normal weight. The polariscopic methods are naturally the most rapid and convenient and are generally used when only one sugar is present or the other optically active substances in the solution are such that they can be readily removed. They find extensive application in the analysis of sugars and sugar products, milk, milk sugar, honeys, etc. Sucrose is almost exclusively determined by means of the polariscope, and when invert sugar is present, as in low grade sugars, the chemist uses the Clerget method, which depends on the polariscopic reading before and after inversion with hydrochloric acid.

Dextrose may also be determined by means of the polariscope; but it must be remembered that the solution, when first prepared, exhibits birotation, which can, however, be destroyed by heating to 100° C. for fifteen minutes.

The quantitative methods, both volumetric and gravimetric, which have been proposed and are to-day used for the determination of the sugars which have the property of reducing an alkaline copper solution, are so varied and numerous and are, as a whole, so well known that I do not believe it neceesary to dwell on them in detail. Exact methods are now adopted for all of the more common reducing sugars, such as dextrose, levulose, invert-sugar, maltose, lactose, etc., and when these sugars occur alone or in mixtures of not more than two, a satisfactory determina-

tion is not difficult. Thus the determination of invert-sugar and cane-sugar when present in a solution has been thoroughly studied, it being found that the sucrose exercises a marked influence on the reducing power of the invert-sugar. The increase in reduction produced has been determined and tables for the correction of the results have been worked out by Meissl, Wein and Herzfeld. Soxhlet found that this increase, due to the presence of the sucrose, only took place when an excess of the alkaline copper solution was used, and has described a volumetric method which yields direct results.

Similarly it is possible to determine two reducing sugars, such as invert-sugar and dextrose, when present in the same solution, by utilizing their property of reducing Fehling's copper and Sacchse's mercury - reagent in different but constant proportions, when the determinations are made under the same conditions. Extreme difficulties however are encountered when the chemist is required to examine complex mixtures, such as infant foods, malt extracts, etc., and in most cases of this kind an exact quantitative separation of the individual carbohydrates is practically an impossibility. It may be of interest to mention a method which can be used with such materials which, although yielding only approximate results, is nevertheless frequently applied and enables a determination of the sucrose, dextrose, levulose, maltose, isomaltose and dextrin in a mixture. The determinations made are as follows:

(1) The reduction with Fehling's solution.

(*a*) in an aqueous solution,

(*b*) after inversion with invertin at (50°–55°C.),

(*c*) in the solution remaining after fermentation with a suitable wine yeast that does not attack maltose,

(*d*) in the solution obtained according to *c* after inversion with hydrochloric acid.

(2) The dextrins by precipitation with alcohol. These data are then used in the following manner:

(*a*) The difference of *a* and *b* = sucrose.

(*b*) The difference of *a* and *c* = dextrose and levulose.

(*c*) The difference of *d* and 2 = maltose and isomaltose.

In connection with this method the polariscopic results often furnish valuable data.

All foods and feeding stuffs contain carbohydrates either soluble or insoluble in water. The former include sucrose, dextrose, levulose, invert-sugar, lactose, dextrins, etc., and are separated by extracting the material with water. The aqueous extract may be evaporated to dryness, the residue less ash representing the total "water-soluble carbohydrates," or the carbohydrates may be separately determined, when it is customary to obtain the reducing power before and after inversion, the first result being stated as "reducing sugar estimated as dextrose" while the sucrose is estimated by means of the difference between the first and second result. When the nature of the sugars present is known, special methods are naturally applied, whereby more accurate data are obtained.

Dextrin, when present in the aqueous solution, is removed and determined by evaporating an aliquot portion to a syrupy consistency and precipitating with an excess of absolute alcohol. The precipitate is dissolved in water and inverted with hydrochloric acid, the dextrose being determined in the final solution.

It is only in recent years that much attention has been given to the methods used in determining the insoluble carbohydrates in foods and feeding stuffs. Previous to this time it was customary, especially with the feeding stuffs, to group all the carbohydrates under the term "nitrogen-free extract," which represented the difference between the total and the sum of the protein, fat, crude fiber, moisture and ash. This method is even now generally followed with feeding stuffs, it being assumed that the carbohydrates all have approximately the same nutritive value. The most important polysaccharids present in foods are starch, the pentosans and galactan. The former two occur in varying quantities in all foods, and the galactan more especially in seeds, where it appears to exercise the function of a reserve-substance.

All of the polysaccharids are hydrolyzed, when treated with an acid, and yield sugar. Thus, the ultimate product

from starch is dextrose; from the pentosans, the pentoses, and from galactan, galactose. The determination of the starch depends on its final conversion into dextrose, and it is evident that in the presence of other polysaccharids a direct treatment with acids will yield an erroneous result. The material must therefore be treated in such a manner as not to attack the other constituents, and this is accomplished by gelatinizing the starch and then saccharifying it by means of a diastase solution. The insoluble portion is removed by filtration, the filtrate inverted with hydrochloric acid and the dextrose determined gravimetrically and calculated to starch by means of the factor 0·90.

The term "pentosans" includes both xylan and araban and is used when the identity of the carbohydrate is not known. Feeding stuffs contain variable amounts of pentosans, and digestion experiments have shown that they possess a definite nutritive value. Thus, Lindsey and Holland (Massachusetts State Report, 1894, p. 175) found them to be practically as digestible as any of the other groups of fodder-constituents, the digestibility varying from 60 to 80 per cent. Stone and Jones (Maine Report, 1893) stated the average digestibility to be 58·2 per cent. The importance of these figures will be appreciated in view of the fact that hay contains from 15 to 20 per cent., wheat-bran from 15 to 30 per cent., and brewers' grain from 20 to 30 per cent.—all being important cattle-foods.

The quantitative method used for the estimation of the pentosans depends on their conversion into furfuraldehyde when distilled with 12 per cent. hydrochloric acid. The furfuraldehyde in the distillate is precipitated by the addition of a sufficient quantity of phloroglucol, the precipitate consisting of phloroglucid, a condensation product of unknown composition. This is collected, dried and weighed. The factors for conversion of the phloroglucid into pentosans or pentoses are based on determinations made with known quantities of the pure sugars and of furfuraldehyde.

Concerning the nutritive value of galactan little appears to be known. This polysaccharid is widely distributed in the plant kingdom, but occurs principally in seeds. Very

little is found in cereals and fodders, while clover seed contains as much as 5 per cent. and lupine seed as much as 12 to 15 per cent.

The quantitative method for the estimation of galactan is based on its eventual conversion into mucic acid. The material is treated with nitric acid of 1·15 specific gravity, which primarily hydrolyzes the galactan with the formation of galactose and then oxidizes this sugar to mucic acid. The magma is digested with ammonia to form the soluble ammonium mucate, which is removed by filtration, and the mucic acid, precipitated by the addition of nitric acid, washed, dried and weighed. It is converted into galactose by the factor 1·33, and this multiplied by 0·9 gives galactan.

The analysis of feeding stuffs also includes a determination of the crude fiber, which is supposed to represent the indigestible portion. The method used depends on a consecutive digestion of the material with boiling 1·25 per cent. sulphuric acid and 1·25 per cent. sodium hydroxid solution whereby all carbohydrates, fats and protein are supposed to be removed. It has been shown, however, that the fiber thus obtained still contains appreciable quantities of hydrolyzable carbohydrates, notably pentosans, and it can therefore be only accepted as an approximate expression of the indigestible constituents, although sufficiently accurate in view of the fact that it is manifestly impossible to imitate the digestive processes except in an exceedingly rough manner.

When a more accurate determination of the cellulose is required it may be obtained by the chlorination method devised by Cross and Bevan.

Briefly stated, a complete analysis of a food or feeding stuff, in so far as the carbohydrates are concerned, will therefore consist (*a*) of the separation of the water-soluble carbohydrates, which are determined individually if needs be, or merely stated as sucrose and reducing sugar,

(*b*) of a determination of the starch,

(*c*) of a determination of the pentosan,

and (*d*) of a determination of the galactan.

Special methods of analysis will be described in connection with the food materials to which they are applied.

The nutritive value of a food depends essentially on three distinct constituents—the proteids, fats and carbohydrates. While it is impossible to express the food value in exact terms, owing to certain indefinite factors such as digestibility, individual idiosyncrasies, etc., we may still arrive at a general expression suitable for comparison by the adoption of tentative factors which König has determined by means of numerous nutrition and digestion experiments, and which are exhaustively discussed in his "Chemie der menschlichen Nahrungs- und Genuss-mittel." These factors as at present used for human foods are:

1 gram carbohydrates = 1 nutritive unit.
1 gram fat = 3 nutritive units.
1 gram protein = 5 nutritive units.

The manner in which these factors are applied with the analysis of a food as a basis is best shown by an example. A kilo of meat is found to contain 200 grams protein, 60 grams fat and 2 grams carbohydrates. It will then contain:

200 grams	protein	× 5 =	1000
60 "	fat	× 3 =	180
2 "	nitrogen-free extract	× 1 =	2
			1182 nutritive units.

If this kilo of meat costs 40 cents, the value of each nutritive unit will be ·0339 cents. The application of these results obtained by the analysis of a food in the calculation of the amount of food necessary to supply the nutrition required by individuals engaged in various occupations, of army rations, suitable inexpensive daily meals, etc., is a subject of such magnitude that it cannot well be brought within the province of this paper. Articles bearing upon this field of research will be found in Elsner, "Die Praxis des Chemikers;" König, "Die menschlichen Nahrungs- und Genuss-mittel," and the valuable series of bulletins containing the investigations of Prof. W. O. Atwater and issued by the office of Experiment Stations of the United States Department of Agriculture.

Voit's investigations may, however, be mentioned as indicating in general the quantity of carbohydrates required in the daily food of individuals. He arrives at the following figures:

	Protein. Grams.	Fat. Grams.	Carbohydrates. Grams.
Laborer, fair health, average work . . .	118	56	500
" good " " " . . .	137	72	352
" " " hard " . . .	137	173	352
Prisoner, little work	100	30–50	300–500
Old person, no work	70–80	30–50	300
Child, 6–15 years old	80	40	250

I have quoted the figures for protein and fat, as the data for carbohydrates would otherwise appear contradictory. The meals given to such persons can be judged with sufficient accuracy by using the figures as a basis, and suitable combinations of foods can be designed, as the average composition of all common foods is sufficiently well known. In cattle foods, the relative value of the carbohydrates, protein and fat, is chosen somewhat differently, it being:

Protein $\times 5 =$ nutritive units.
Fat $\times 5 =$ " "
Nitrogen-free extract $\times 1 =$ " "

Thus, if we have a cattle food costing $1 per 100 pounds, and the analysis shows it to contain 15 per cent. protein, 5 per cent. fat and 25 per cent. nitrogen-free extract, the value of the nutritive unit will be calculated as follows:

$$\frac{100}{[(15 + 5) \times 5] + 25} = .8 \text{ cent.}$$

The Carbohydrates in Foods as a Basis for the Detection and Estimation of Adulteration.—There are probably few foods which suffer an adulteration in which an analysis with reference to the sugars or other carbohydrates is not indicated, and often absolutely necessary. In many cases the latter are directly used as an adulteration, and in others, the pure food is known by experience to contain a certain percentage of carbohydrates, the limits within which these constituents vary having been established, so that a quantitative determination frequently furnishes valuable indications. In discussing the practical application of the results

obtained and the judgment of the various foods, I have thought it best to treat the latter in classes. We have, so far, unfortunately, no federal law with appropriate food standards in this country, although various States have adopted certain regulations which naturally lack uniformity and, furthermore, cannot control interstate commerce. I have therefore been forced to draw freely from the German regulations and standards, with which the provisional analytical methods adopted at the last convention of the Association of Official Agricultural Chemists agree in the main points.

Meats and Meat Products.—The analysis of meat products, such as canned meat, sausages, chopped meat, etc., must take into consideration two possible methods of adulteration, which are the addition of horse-meat, or of starch or flour, the latter applying more specifically to canned goods and sausage. The use of horse-flesh is very commonly practised in France, Germany and Austria, although the dealers are supposed to declare such addition. While in no sense deleterious to health, these adulterations are clearly financial frauds. The detection of an addition of horse-flesh is difficult, and most of the methods proposed depend on the fact that this meat contains more glycogen than other meats. These methods will give fairly accurate results if the meat is absolutely fresh, but become practically valueless when the meat has been kept for some time, because the glycogen rapidly disappears after death, probably being converted into dextrose. A qualitative test* may be made by boiling the meat with an equal volume of water and testing the filtered broth with a few drops of a potassium iodid-iodin solution (two parts iodin, four parts potassium iodid and 100 parts water). In the presence of glycogen a dark-brown color is developed which disappears on cooling. When starch is present it should be precipitated by adding two volumes of glacial acetic acid. Niebel† considers all color tests to be merely confirmatory in connection with the

* Bräutigam and Edelmann, "Pharm. Centralbl.," 1893, 557.
† "Ztschr. Fleisch u. Milch-Hygiene," 1895, 86.

quantitative determination. Most of the quantitative methods are extremely tedious and the Mayrhofer method* is probably most convenient and, at the same time, sufficiently accurate.

A preliminary examination for starch should always be made by means of the microscope and iodin solution, and when this is absent, the glycogen may be determined as follows:

Fifty grams of the meat or sausage is treated with 8 per cent. alcoholic potassium hydroxid solution, diluted with warm 50 per cent. alcohol and the precipitate collected on a filter and washed with strong alcohol. The residue is dissolved in an aqueous potassium hydroxid solution, slightly acidified with acetic acid and mixed with an excess of alcohol. The precipitated glycogen is washed with alcohol and ether, dried and weighed. It must be a white amorphous powder containing neither nitrogen nor ash. The aqueous solution must have a white opalescence, must give a deep-red color-reaction with iodin and must not reduce Fehling's solution.

In the presence of starch, which is frequently added to canned meats and sausages, this method can, however, not be used, as the starch is also precipitated. With such materials the Niebel-Salkowski method† gives satisfactory results, although it is very tedious and time consuming. According to this method the meat is dissolved in a 1 per cent. aqueous potassium hydroxid solution, which is exactly neutralized. The proteids are removed by repeated treatments with Nesslers solution and the glycogen is precipitated in the filtrate by means of alcohol. As previously stated, the glycogen rapidly disappears from the fiber after death, and all these methods may yield negative results even when horse-meat is present. When such an addition is suspected, it is therefore always necessary to determine the reducing sugar by digesting a weighed portion of the meat with cold water and estimating the dextrose in the filtered

* "Bujard, Forschungsber." 1897, 47.

† "Ztschr. Fleisch u. Milch-Hygiene," 1891, 185.

extract in the usual manner. To this is added the dextrose equivalent to the glycogen found (10 glycogen—11 dextrose), and according to Niebel, the presence of horse-meat is proved when the total sugar exceeds 1 per cent. of the fat-free dry substance, the limit being based on numerous analyses of various meats, which have shown that absolutely fresh meat in which the action of the enzyme, which converts glocogen into dextrose has been arrested by immersion in boiling water, contains only traces of dextrose.

In no case should a determination of the glycogen or reducing sugar be accepted as sole proof of the addition of horse-flesh. It is at the most only corroborated evidence in connection with the other analytical data obtained.

Sausages are frequently adulterated by the addition of an excessive amount of starch or flour. This adulteration enables the manufacturer to use a poor grade of meat, as the gelatinization of the starch during cooking accomplishes the intimate combination of the constituents otherwise not attainable, and also permits the incorporation of a larger proportion of water without affecting the outward appearance of the product. This form of adulteration is primarily a financial fraud, which is the more serious when we consider that meat in this form is consumed more extensively by the poorer classes. The health of the consumer is furthermore endangered, as the large proportion of gelatinized starch present causes the product to deteriorate rapidly. A preliminary examination is in most cases sufficient and may be made with the microscope, using iodin, or by applying the reagent directly to a freshly cut surface. When a considerable quantity of the adulterant is present, as will be generally the case, the surface will be colored a deep blue wherever the iodin has penetrated. The isolated, hardly noticeable blue spots which, in the absence of added starch or flour, are due to the starch naturally present in the condiments, such as pepper, can in no case render the result doubtful.

The quantitative determination of the starch present, either as such or as flour, cannot be made by the diastase method, as has been recommended, since it has been found

that the final solution obtained contains some constituents derived from the meat which retard the precipitation of the cuprous oxid and thus lead to a low result. The exact nature of these compounds is not understood, but experiments made in the Bureau of Chemistry of the Department of Agriculture proved conclusively that when a known amount of starch was added to chopped meat it could never be fully recovered by this method. A modification of the Mayrhofer method for glycogen, reference to which was just made, can also be used for starch and appears to be satisfactory. Extreme accuracy is naturally not required, as such a sophistication, if practised at all, is carried to such an extent as to condemn the product even though a large error may accompany the analysis. In this connection it must not be forgotten that in some sections a small quantity of starch or flour is always mixed with sausages, this being in accordance with general practice and the demands of the consumers. While it is, therefore, impossible to establish an absolute limit for the amount of starch or flour in these foods, a certain arbitrary maximum must be fixed. In certain districts of Germany this is placed at 2 per cent., while in others no addition whatever is allowed. The starch which is present through the addition of condiments, such as pepper, pimento, etc., rarely exceeds 0·4 per cent., and therefore never endangers the reliability of the analysis.

Milk and Milk Products.—The determination of the milk sugar or lactose has little value, in so far as the detection of adulteration is concerned, and is therefore rarely required. The quantity of lactose in normal milk varies from 3·5 per cent. to 5·5 per cent., and with individual cows the variations are still greater, depending on different circumstances, such as race, method of feeding, lactation, general health, etc. Isolated cases are reported where skimmed milk has been adulterated by the addition of starch or flour, so as to impart a creamy appearance. When such an addition is suspected, a microscopical examination of the sediment is sufficient to detect the fraud and a quantitative analysis is not required. Skimmed milk is also adulterated occasionally by adding cane-sugar.

The sucrose can be determined by inverting it with some agent which does not attack the lactose.* Either citric acid or dilute hydrochloric acid can be used, the polarization being determined before and after the inversion. Another method,† which is frequently used by German chemists, also depends on inversion, but uses hydrochloric acid and prolongs the action of the acid until all the lactose is converted into invert-sugar. The amount of invert-sugar due to the lactose present is calculated and deducted from the total found. All of the gravimetric methods probably yield only approximate results, owing to the fact that the reducing power of a sugar is in general materially influenced by the presence of another sugar. When a determination of the total sugar shows a milk to contain more than 6 per cent., it may be declared adulterated. It is highly improbable, however, that this rather expensive form of sophistication is practised to any extent.

Condensed milk is prepared by the evaporation of normal milk to the required consistency with the addition of 25 to 50 per cent. of cane-sugar. In the ordinary routine of food inspection it is generally sufficient to calculate the total sugars by differences, but a complete analysis may occasionally be required when the lactose and sucrose can be determined with sufficient accuracy by the methods above described. The average of a number of analyses shows condensed milk to contain 16 per cent. lacrose and 31 per cent. of sucrose.

Butter is very rarely adulterated by the addition of such materials as starch or flour. Glucose is frequently used as a preservative, especially in butter prepared for export trade, in which Crampton‡ reports as high as 10 per cent., and quite recently the chemist in charge of the dairy laboratory in the Bureau of Chemistry, U. S. Department of Agriculture, has found a number of samples adulterated in this manner, although the amount of glucose present in no case

* "Leffman and Beam, Food Analysis," page 228 et seq.

† "Bujard and Baier, Hilfsbuch für Nahrungsmittelchemiker," Ed. 2, p. 122.

‡ *Jour. Am. Chem. Soc.*, 1898, 207.

exceeded 4 per cent. These samples were all labeled butters — *i. e.*, butters which are prepared by mixing a number of shipments of different colors. To detect the addition of glucose the melted butter is shaken repeatedly with hot water and the reducing sugar determined in the water extract. It must be remembered, however, that normal, unsalted butter will contain as much as 1 per cent. of milk sugar.

Cheese is occasionally adulterated by the addition of flour, starch or ground potatoes. The microscopical examination readily detects such an adulteration, and may be made on the residue left after digesting the suspected sample with ammonium hydrate, in which cheese is almost completely soluble.

Flour and Breadstuffs.—It is very doubtful if flour is to-day adulterated to any extent. Previous to the passage of the Federal flour law the adulteration had assumed considerable proportions, especially with wheat flour intended for export trade. The substitution then consisted principally of cornflour or cornstarch, the latter being sold for the purpose under the trade-name of "flourine." This form of adulteration became so extensive that it was sharply attacked by European officials and, as a natural sequence, caused a material decrease in the exports of American wheat flour.

The presence of a foreign flour in the sample under examination is most conveniently detected by means of the microscope, the form and size of the starch grains of each cereal being sufficiently characteristic to be recognized by the experienced microscopist. The addition of rye or maize flour to wheat flour can be shown by the Baumann method,* which depends on the property of wheat starch of gelatinizing completely when one gram of flour is shaken for two minutes with 10 cubic centimeters of a 1·8 per cent. potassium hydroxid solution. After partial neutralization of the alkali a drop of the mixture is examined with the microscope, when the rye or maize starch, if present, will be found practically intact. A number of qualitative color-tests have

* "Ztschr. für Untersuchung der Nahrungs- und Genuss-mittel," 1899, 28.

also been proposed. The presence of potato flour or wheat flour may be detected by rubbing the sample with water until a stiff paste is obtained, which is thinned with water and filtered. The filtrate, when tested with iodin, becomes deep blue when potato flour is present, while with pure wheat flour, only a yellow to orange is obtained. Buckwheat flour is frequently mixed with rice flour, and this may be detected by preparing a thin paste with water and adding a solution of calcium hydroxid. Pure buckwheat is colored dark green, changing to red on the addition of hydrochloric acid. Rice flour, similarly treated, gives a yellow color, which is destroyed by hydrochloric acid. A mixture of the two flours yields intermediate colors. All color-tests should be used very cautiously, however, when judging of an adulteration and should not of themselves be considered absolute proof.

The final decision should always be based on a careful microscopical examination. Even when no adulteration is present it is necessary to carefully observe the starch grains. They should be normal in size and appearance and shrunken grain, or grains which are swollen through the presence of an excess of moisture, should be absent, as these are proof of a deterioration in the quality of the flour. Flour which contains a considerable quantity of such starch will produce a bread prone to early decomposition, although a very thorough baking may prevent this.

The statements with reference to the examination of flour apply also to bread and the various breadstuffs. The detection of foreign flours is, however, attended with considerably more difficulty, as the starch grains suffer almost complete destruction during the process of baking, so that absolutely conclusive results can rarely be obtained.

Infant foods, most of which are mixtures of desiccated milk with flour in which the starch has been rendered partially soluble by treatment with steam and pressure, or the action of acids or diastase, are at present offered to the public in great variety. The chief claim made by the manufacturers of these foods is that they are easily digested and quickly assimilated. Their nutritive value depends mainly

on the percentage of soluble carbohydrates present, and the method of preparation should always be such as to carry this to the highest attainable point. The analysis of these foods includes a microscopic examination for unchanged starch, and a determination of the soluble and insoluble carbohydrates and preparations are frequently found which are flagrant deceptions, consisting merely of ordinary grades of flour. The soluble carbohydrates are generally determined by digesting the material, after removal of the fat, with 50 per cent. alcohol and determining the total solids in the filtered extract, the ash being deducted. The insoluble residue serves for the determination of the starch in the usual manner. No attempt is usually made to separate the soluble carbohydrates quantitatively, owing to the complex nature of the mixture. The great variety of materials used in the preparation of these foods makes it impossible to fix any definite standards as regards composition.

Sugars.—The extensive class of human foods whose nutritive value depends on the presence of sugar and which includes the various grades of refined sugar, syrups, molasses, maple sugar, honey and confectionery, is naturally one of the most important as regards the analytical methods used for the determination of the carbohydrates. One of the most important applications in this respect is the analysis of sugars, syrups and molasses imported into this country and subject to duty. The present tariff law imposes a duty of $\frac{95}{100}$ of a cent per pound on all sugars not above 16 Dutch standard in color, tank-bottoms, cane-syrups, melada, concentrated melada, concrete and concentrated molasses testing not above 75 polariscopic degrees and an additional $\frac{35}{1000}$ of a cent for every degree above 75°, fractions of a degree being taxed proportionally. Refined sugars and sugars above 16° Dutch standard are taxed $1\text{-}\frac{95}{100}$ cents per pound. Molasses which polarizes above 40° and not above 56° pays a duty of 3 cents per gallon, and molasses which has a polarization above 56° of 6 cents per gallon. It is therefore evident that extreme accuracy in the sampling and analysis of the importations is highly important, and detailed regulations concerning the method to be pur-

sued have been issued by the Treasury Department. With high-grade sugars, either beet or cane, a direct polarization is sufficient, but with low-grade second and third sugars, molasses and similar products, the material should be polarized before and after inversion, the Clerget method being used.

The highly refined sugars are probably never adulterated. The only substitution which could be practised would be the addition of dextrose, and this is precluded on account of the hygroscopic nature of the adulterant. Powdered sugar is occasionally found which has been adulterated by the addition of starch. The fraud is easily detected by dissolving the sample in cold water and examining the sediment with the microscope.

The chief adulteration of such foods as table syrup, maple syrup, honey and molasses consists of the addition of varying amounts of glucose.

With reference to molasses, we may assume as preliminary indications of adulteration that light-colored molasses which polarizes higher than 60° is almost certain to contain glucose; that a dark-colored molasses should polarize below 50°, and that any molasses which gives a right-handed reading after inversion is unquestionably adulterated.

The addition of commercial glucose to a syrup or molasses introduces another difficulty in the analysis, in that it renders the value of both the polarimetric and gravimetric determination of the sucrose rather problematic. The adulterant contains usually from 28 to 45 per cent. dextrin, and it is evident that at least a portion of this constituent is converted into dextrose during the process of inversion, thereby affecting both the polarization and, when the gravimetric method is used, leading to an erroneous result in that this dextrose will be reckoned as sucrose.

The presence of glucose in a syrup or molasses can be easily detected by the polarization before and after inversion, the inverted solution being read both as near as possible at the temperature of the direct reading at 87°, at which temperature the rotary power of the invert-sugar formed from the sucrose equals 0. A pure syrup or molas-

ses will always give a left-hand reading after inversion, and at 87° the reading will be zero or very nearly so. When glucose is present, however, the reading after inversion will be strongly dextrorotatory at 87°, owing to the dextrose and the dextrins of high specific rotatory power which are present in the adulterant.

Another method for the detection of glucose depends on the removal of all sugars by fermentation with yeast whereby the final solution contains pratically no optically active substances except the non-fermentable dextrorotatory constituents, which are always present in commercial glucose. Of all the various methods proposed from time to time this is probably the most generally used and the most reliable, although the result is naturally purely qualitative and does not enable the chemist to form any opinion as to the quantity of glucose present. This is, however, not essential, the proof of adulteration being sufficient to condemn the food. The method is described by Sieben as follows:

Twenty-five grams are dissolved in 200 cubic centimeters of water, sterilized and mixed with about 5 cubic centimeters of starch-free beer yeast. After fermentation at about 20° C. the liquid is clarified, diluted to 250 cubic centimeters and filtered, 200 cubic centimeters evaporated to 50 cubic centimeters and polarized when it should exhibit only a slight dextrorotation. Another portion is inverted with hydrochloric acid and the reducing sugar determined gravimetrically when only traces should be obtained.

Among the non-fermentable substances present in commercial glucose are found gallizin and amylin, and they are in general believed to be detrimental to health, although this point has so far not been decided definitely.

[*To be concluded.*]

The "Series-Vapor" and "Heat-Waste" Engines, as Supplementary to Single-Vapor Engines.

By R. H. Thurston,
Honorary Member of the Institute.

(*Continued from p. 314.*)

Case IV—Constant Temperature-Range with the Rankine cycle and a properly adjusted terminal pressure gives the quantities tabulated as below:

TABLE IV.

Vapors.	t_1	t_2	t_3	t_4	t_5	τ_1	τ_2	τ_4
Water	342	194	104	293	248	803	655	754
Alcohol	342	158	104	293	248	803	655	754
Ether	342	122	104	293	248	803	655	754
Carbon di-sulphide	342	140	104	293	248	803	655	754
Chloroform	342	140	104	293	248	803	655	754

Vapors.	τ_3	p_1	p_2	p_3	p_4	p_5	λ_1	λ_2
Water	709	17,310	1,442	153	8,705	4,103	869·4	975·6
Alcohol	709	33,712	1,507	373	17,989	9,003	286·2	397·8
Ether	709	65,328	3,524	2,526	36,090	21 501	99·4	158·1
Carbon di-sulphide	709	36,708	3,245	1,721	22,943	14,342	108·2	141·2
Chloroform	709	29,845	2,092	1,020	18,433	10,936	92·6	130·0

Vapors.	λ_4	λ_5	K.	D_1	D_2	D_4	D_5	v_2
Water	908·5	940·7	1	·317	·029	·164	·081	9·37
Alcohol	311·6	336·2	·966	1·572	·171	·866	·447	18·59
Ether	116·3	130·1	·607	4·911	·903	2·798	1·717	18·53
Carbon di-sulphide	120·1	130·0	·257	2·832	·623	1·827	1·180	8·25
Chloroform	94·0	98·8	·246	3·611	·695	2·301	1·405	12·23

Vapors.	v_4	v_5	W	H	E	F	M
					per cent.		
Water	1·83	3·57	54,829	272,528	20·12	11·44	1
Alcohol	1·83	3·54	127,592	592,904	21·52	24·40	·853
Ether	1·85	3·11	202,506	910,954	22·23	48·02	·535
Carbon di-sulphide .	1·47	2·18	87,758	368,310	23·83	63·88	·550
Chloroform	1·58	2·60	94,793	410,058	23·12	75·42	·761

The quantities and the accompanying diagram, exhibiting the same facts graphically, are peculiarly interesting in this connection. In these comparisons, we find steam at a

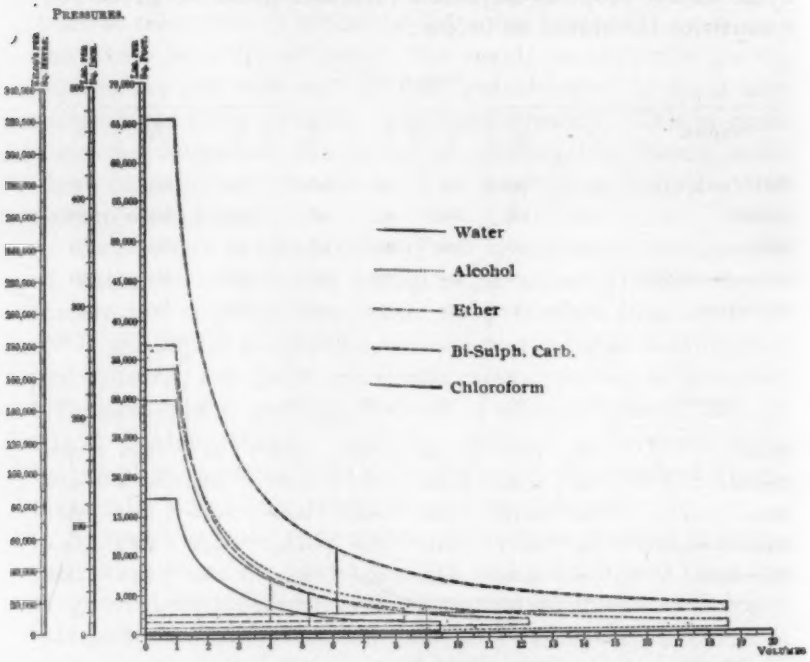

FIG. 3.—**Rankine cycles. Temperature-range common.**

disadvantage in efficiency, because of its restriction of pressure-range at its upper limit, the more volatile fluids having an advantage of several per cent.; while it is also at a disadvantage in respect to size of engine required for the same amount of power. It is now perhaps more easily

seen just where the advantages of a possible utilization of a more volatile fluid may be found, either as with the Campbell engine, in a simple construction, or as in the Du Trembley and other plans, as a series-vapor system.

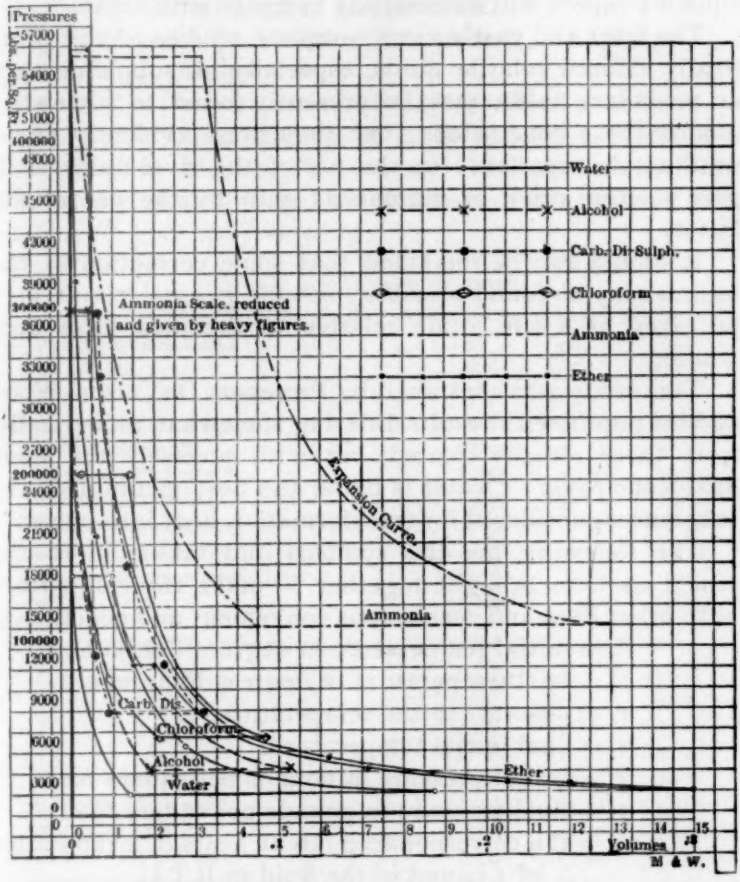

FIG. 4.—**Carnot cycle. Common T_1-T_2 and H.**

Regarding the use of either vapor to the exclusion of steam, the investigators whose work is here summarized, reach the following conclusions:

(1) Steam, within the limiting pressure-range customary with the steam-engine of to-day, is the most desirable working fluid.

(2) The advantages of the non-aqueous vapors, proposed as substitutes for steam, may be gained with the latter by increase of initial pressure.

(3) The general deduction is, that "none of the non-aqueous vapors will successfully compete with steam."

The later and vastly more complete studies of the practically utilized volatile fluids, especially as supplementary or secondary fluids, may be presently found to somewhat modify these conclusions; but they must evidently stand until ample experience in the use of the rival fluids shall give positive proof of permanent gain by the use of the latter.

It should also be remarked that some correction of the figures may be found possible; but the general result may be taken as a safe guide relative to the ideal case here studied.

This study was continued by Professor DeVolson Wood and his pupils, with results differing somewhat, numerically, from those already quoted, but with precisely the same final conclusion: "water is by far the best medium of the substances considered for transformation heat into power.*"

The following are the symbols and tabulated results which are here brought together to make the comparison with other data and conclusions convenient and conclusive:

T_1 = initial temperature in degrees Fahrenheit.
T_2 = final temperature in degrees Fahrenheit.
τ_1 = absolute initial temperature.
τ_2 = final initial temperature.
p_1 = initial pressure in pounds per square foot.
p_2 = final pressure in pounds per square foot.
h_{e1}, h_{e2} = the corresponding latent heats of evaporation of 1 pound of the fluid in B.T.U.
H_{e1}, H_{e2} = latent heats of 1 pound in foot pounds.
L_1, L_2 = latent heats of 1 cubic foot in foot pounds.
w_1, w_2 = weights of 1 cubic foot of vapor.
v_1, v_2 = volumes that the fluid would occupy if it were all vapor.

* "Transactions A.S.M.E.," Vol. XII, 1890.

u_1, u_2 = initial and final actual volumes.
K = mean specific heat of the liquid between the temperatures τ_1 and τ_2.
W_E = total work of expansion.
W_C = total work of compression.
H = the heat used in foot pounds.
E = efficiency.
J = dynamic unit of heat = 778 foot pounds.

Studies of these efficiencies, made under the direction of the writer, by Messrs. Flowers and Walton, in which the formulas of Rankine and the methods of the writer * were employed, give the following:

TABLE V.—BINARY ENGINES.

CYCLES CORRESPONDING TO NON-CONDENSING STEAM-ENGINE.

P_1 (per square inch)	100	300	500
T_1 (F. abs.)	788·6	878·4	928·4
T_2	587·0	587·0	587·0
$T_1 - T_2$	201·6	291·4	341·4
Carnot efficiency	25·54	33·10	36·8
Rankine efficiency †	12·53	20·80	23·60
Recorded by ether	87·47	79·20	76·40
Ether cycle efficiency	11·50	11·50	11·50
Combined efficiency	22·58	29·91	32·39
Steam per horse-power hour	10·18	6·96	6·23
B.T.U.$_1$	11,270	8,500	7,800

CYCLES CORRESPONDING TO CONDENSING STEAM-ENGINE.

P_1	100	300	500
T_1	788·6	878·4	928·4
T_2	531·0	531·0	531·0
$T_1 - T_2$	257·6	347·4	397·4
Carnot efficiency	32·7	39·58	42·8
Rankine efficiency †	12·53	20·80	23·60
Recorded by ether	87·47	79·20	76·40
Ether-cycle efficiency	17·42	17·42	17·42
Combined efficiency	27·76	34·60	36·91
Pounds steam	8·28	6·02	5·46
B.T.U.	9,167	7,355	6,895

The accompanying diagram exhibits the progress-curve for these cases, the efficiencies rising rapidly at the lower

* "Manual of the Steam-Engine;" Vol. I, Chap. IV.

† Steam, dry and saturated, as in Rankine's "jacketed engine."

ranges of pressure and tending to become asymptotic with the base-line in the upper ranges—a familiar fact but often overlooked. The comparatively small gains in the more radical practice evidently point to a limit at which, in all cases, we approach a balance between gains and losses, direct and incidental. The practical limit of the commercial case is often far within that of the ideal, purely thermodynamic case. In the present instance, the practical is more closely approximated to the ideal through the facts that the ether normally superheats with expansion, and that

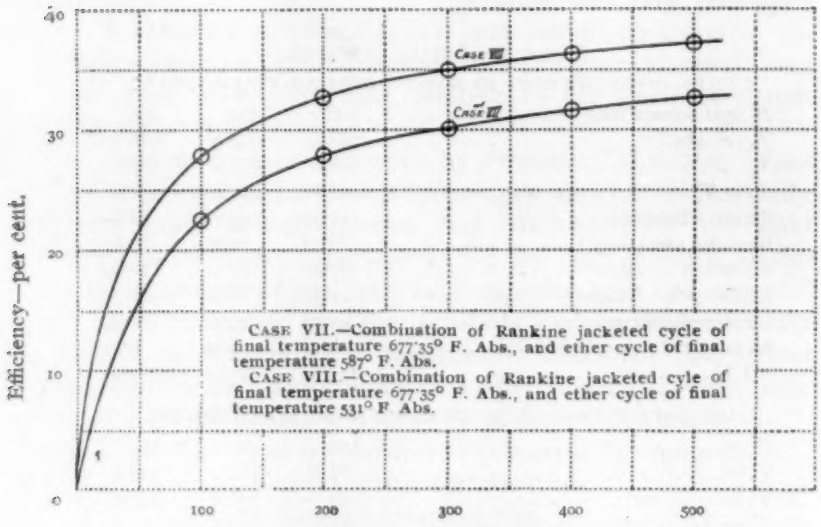
40
30
20
10
0
Efficiency—per cent.
CASE VII
CASE VIII
CASE VII.—Combination of Rankine jacketed cycle of final temperature 677·35° F. Abs., and ether cycle of final temperature 587° F. Abs.
CASE VIII.—Combination of Rankine jacketed cyle of final temperature 677·35° F. Abs., and ether cycle of final temperature 531° F. Abs.
100
200
300
400
500
Initial steam pressure in pounds on the square inch.

FIG. 5.—Combined engine efficiencies.

its latent heat of vaporization is low, giving high pressures at the minimum of the temperature-range. In the above case, also, the back-pressure remains high and the opportunity for still higher economy is seen. But a comparison of the figures given for efficiency by these investigations indicates a comparatively close approximation to the ideal for the combined system.

The Finance of the Case is influenced by several distinctly different considerations—in part internal, in part external—

partly relating to costs and prices of constructions and heat-stores; partly to values and costs of rejected heat and profits of use of the heat-economizing system. It is evident that in some cases it may be found that the saving effected by the use of the system proposed may prove to be small, or actually zero, or even a negative quantity, depending upon the magnitude of the waste, the cost of its reduction and the value of alternative methods.

Primarily, the question is one of choice between one and another method of economy and the resultant value of the rejected heat. It may be the fact that the heat rejected has as great value for other purposes, as for heating, for example, as has the prime steam. In such case, it is not a matter of economy to save it at all, and it may be that a non-condensing engine, rejecting sufficient heat to satisfactorily meet the demand for heating, or in a woolen mill, for the dye-houses, will prove a more economical machine than the most perfect of condensing engines wasting heat from its hot-well. Where the rejected heat may be in any way so utilized as to make its value equal to, or nearly equal to, that of steam direct from the boiler, the net result is the equivalent of that obtainable with a heat-engine of efficiency *unity*. Condensers and "heat-waste" accessories are, in such cases, costly and wasteful adjuncts.

In a large proportion of our electric light and power distributions, the steamplant wastes a very large part, often 75 to 85 per cent. of the energy of the fuel, or even more, in some instances; and this waste may frequently be substantially all saved by diverting the rejected heat into a heating system for the adjacent properties. In numerous cases, if not in most, a choice of methods of saving rejected heat is offered the engineer, and it becomes his duty to select that which, all things considered, will give the most satisfactory return when viewed from the standpoint of the investor in after years. This may mean complete utilization, or complete waste, of the rejected heat; it may compel the use of a non-condensing and inefficient engine for a good modern high-pressure plant; of the condensing-engine, or of the most refined construction of steam-engine, reinforced,

as at Berlin, by a "heat-waste" accessory. The right decision is, in fact, determined by financial considerations and is absolutely definite for each case. The engineer's duty is that of identifying that precise solution of the problem. A steam-engine introduced into the line connecting a battery of boilers employed for heat, or for use in dyeing and bleaching, with its work will abstract simply the mechanical equivalent of its power from the passing current of steam, and the balance will be none the worse for the loss; while the engine will produce its power with unity efficiency, giving to work 778 foot-pounds per B. T. U. thus abstracted. If, under usual conditions, the horse-power costs $30 a year, where the efficiency of the heat-engine is 20 per cent., in this case the crude non-condensing machine will provide it for $6. With lesser values of heat rejected and higher costs of its production, the comparison changes in the direction of justification of expense incurred in its utilization of otherwise lost energy. With high cost of production and high values of power produced, large costs may be profitably incurred in the provision of a system by which to economize the wastes, even of a good condensing-engine.

The absolutely ideal method of employment of thermodynamic machines, subject, as are all known forms, to an unavoidable waste of a large amount, is to use them where there exists a demand for a constant supply of steam or heat, for other purposes, of more than equal quantity with their wastes, and securing unity-efficiency by placing them, as above, in the path of that heat-supply. This system will often be found entirely practicable, under existing conditions, and may very often be made practicable by proper combinations of industries requiring heat and steam in considerable quantity.

In every field of engineering, the fundamental principle which limits progress in promoting efficiency is: Improvement may be carried to that point at which further advance will cost more than the gain, and at which a lesser efficiency would mean a sacrifice of economy more than equal to the saving in cost. This particular improvement will find its limitation in application under any given conditions at this

financial critical point, however successful, practically, it may prove to be.

The Limit of Expansion.—As in all heat-engines, the terminal pressure on the expansion-line is fixed in the series-vapor engine for each individual case by the principle which asserts that the limit is reached when the income of the plant, or its net output per unit of cost, would be reduced by either increasing or diminishing the ratio of expansion. The limit is set in practice more commonly by that at which the consumption of heat, steam and fuel per horse-power-hour would be increased by such variation from the limit; which latter is not a correct solution of the problem.

The terminal pressure is found by experience, as a general rule, to be not far from one-third of an atmosphere in excess of back-pressure at about 6 or 8 pounds per square inch absolute, in the condensing engine, and 20 pounds or more for the non-condensing engine, when maximum economy of fuel is sought, and probably considerably higher in many cases, on a correct commercial basis; but it is very variable with varying conditions of the market for fuel, for construction and for capital and labor.

With the series-vapor engines, the profitable limit is usually elevated by their higher cost to a figure somewhat above that for steam. Its exact magnitude must be a subject of investigation in the individual case. The advantage gained by the use of these vapors when accessory to steam, as in the binary-vapor engine, is that of securing the desired limiting pressure at a lower point on the temperature-scale. This means the extension of the heat-transformation through a wider range of temperature and a corresponding gain in thermodynamic efficiency. This effect is precisely the same, so far as thermodynamic action is concerned, as the extension of the temperature-range for the single vapor in the steam-engine. It is thus entirely correct to assume that the steam-engine of equivalent value is that in which this range is to this extent widened, and to compute the efficiency of such a steam-engine as being that of the proposed equivalent series-vapor engine and to accept comparisons on this basis.

Experience with the steam-engine shows that, with that machine, at least, and presumably with every machine in the class, there is a certain terminal pressure in the working cylinder, below which it is undesirable, on economical grounds, to expand the working fluid; since any gain of work is more than compensated by added wastes by friction and other losses. In steam-engines of the larger sizes and better class, this limit is found at a terminal pressure of from 5 to 8 pounds above the back-pressure, in marine practice, and, especially when the accessory wastes of transmission and of finance are taken into account, it is likely that the figure should be at least 50 per cent. higher; while in small and cheaply constructed machines, and where fuel is cheap and machine-work costly, still higher terminal pressures are representative of best practice. Presumably the same principle holds, and in about the same measure, in the binary vapor-engine. The "waste-heat engine" in its ideal form, may be defined, therefore, as one in which, by suitable choice and use of working fluids, the net effective pressure of the expanding fluid, despite falling temperatures and transformation of heat into work, is maintained at magnitudes considerably in excess of the limiting terminal pressure for the engine. That secondary fluid in this respect is best, other things equal, in which the final pressure at the lower limit of available temperature in the working cylinder is highest, that is to say, the most volatile.

Another method of stating the principle of the multiple-vapor-engine is found in the assertion that the main purpose of the complication is that of securing increased terminal pressures with a view to elevating the mechanical efficiency of the engine. The use of vapor, or of a series of vapors, therefore, in which, as temperature falls, the correspondent pressure shall relatively rise, is the obvious means of accomplishing this purpose.

Available fluids include ammonia, chloroform, sulphur dioxide, ether, carbon di-sulphide, and, in fact, any fluid having a low boiling-point at ordinary pressures. A whole series of petroleum products may be included as available in a "series-engine," as the writer has called it, where, as

has sometimes been proposed, notably by Wellington, a multiple-cylinder engine is provided with a "multiple-series" of such substances, each adapted by its special relations of temperature and pressure to its appropriate cylinder and the boiler for each of which serves as the condenser for that next higher in the series.

Each of the known available secondary or series-fluids has its own objection, however, and often more than one. All are costly—some, dangerous—from their physical qualities, as illustrated by the stifling properties of ammonia, the peculiar effects of chloroform, the inflammable nature of the petroleums. These objectionable properties may prove fatal to general employment in this class of heat-engine, even though otherwise entirely satisfactory. Probably their costs are not likely to prove very objectionable, as once introduced into the apparatus, they circulate constantly, without any other loss than that by leakage, and this may prove not to be an insurmountable difficulty of construction, notwithstanding the fact that the surface condenser is commonly now composed of tubes fitted into tube-sheets, thus compelling the user to deal with numerous joints. The joints may be either suppressed or made safe against liability to sensible leakage. The danger of accidents, permitting deleterious substances to find their way out into the surrounding atmosphere, may prove less easy of avoidance. This risk, which has led to the use of the air-refrigerating machines, in place of ammonia-machines, on shipboard, is one to be seriously considered in the choice of secondary fluids. The magnitude of this and of other insurance risks, and their financial evaluation, become elements of the problem of "maximum commercial efficiency," the ultimate problem of the engineer, here as everywhere else.*

A multiple-fluid engine, including a gas-engine—from which, as a rule, one-half of the heat of combustion is discharged by way of the jacket, the waste heat being ejected

* Commercial Efficiencies: "Manual of the Steam-Engine," R. H. Thurston.

at a very high temperature both into the jacket and through the exhaust—presents the very best of opportunities for utilization of the series principle. Such a series might be illustrated in a supposable case in which the heat rejected from the gaseous working fluid should produce steam for use in an accessory steam-engine, this in turn to reject its waste heat into an ammonia or a petroleum engine and this, again, into other engines, in sequence, employing lighter petroleums, and, possibly, terminating the series with an ether or ammonia engine. Such series-engines have often been proposed, but none have proved commercially persistent.

In the earlier days of the steam-engine there was comparatively little opportunity to introduce the vapor-series engine and little inducement to seek utilization of waste heat. The wastes were large in quantity and due to crudeness of design and to conditions generally capable of large improvement without change in the type of engine. The time for the series-engine had not arrived. Possibly this may prove to be the fact to-day; but conditions have greatly changed, and it may prove practicable as well as expedient to endeavor to utilize the still large amount of waste heat rejected from the engine between the temperatures of the condensing water and that of the terminal pressure on the expansion line, notwithstanding the fact that this may involve the adoption of more elaborate constructions and of more refined systems of heat-transformation.

An important practical condition, affecting seriously the availability of the series-fluid engine, is the difficulty of avoiding in those elements of the series which have a terminal pressure lower than atmospheric, the leakage of air into the system and the resultant vitiation of the vacuum in the condenser. Thus, in the steam-engine, the minimum temperature of hot-well and condenser is usually not far from 110° F., and the vacuum at the sea-level is usually not higher than 25 or 26 inches, although 27 is sometimes attained and still more rarely maintained. The condenser, when absolutely tight and free from air, would exhibit a

vacuum of about 28 at the lower temperature, and the higher temperature, 130° or 140°, corresponds to the actual vacuum observed—about 24 inches—without leakage. It is not to be expected that any vacuum obtainable from the accessory fluids will be less affected by leakage. On the other hand, it is to be observed that the suppression of leakage may result in the increase of the mean effective pressure of the steam-engine by from 2 to 5 per cent. and with the multiple-fluid engine in some further exaltation of the pressures accompanying the lower temperatures of working fluid.

The suppression of leakage can now be effected vastly more completely than in Rankine's time, as finer workmanship and more perfect systems of packing of piston-rod and valve-stems now enable the builder to put into the hands of the user a practically tight machine. This improvement in apparatus affords opportunity to improve both the older and the newer form of heat-engine, and the latter even more than the former. Similarly improved methods of construction permit the reduction of the costs of the more complicated machine, thus aiding in making necessary complications more unobjectionable on that score. The commercial failure of an improved construction at the middle of the century is thus not a proof of unavailability at its end, and is no bar to repetition of the experiment.

The Use of Volatile Fluids, as primary or secondary working substances for heat-engines, where comparatively low temperatures were to be dealt with, was suggested a century ago by Sir Humphrey Davy, who proposed thus to utilize the wasted heat of the water of condensation discharged from the steam-engine, making that element of the machine the boiler of a secondary engine—of a "waste-heat engine," as it is coming to be called.

The idea was taken up by Mr. Ainger in his lectures, about 1830, before the Royal Society, and his suggestion was that *ether* should be employed as the secondary fluid in carrying out the plan of Davy. Since that time numerous scientific men and inventors have adopted the idea, and a considerable number of binary-vapor engines have been

constructed, in which ether, chloroform, ammonia and other volatile fluids have been employed, more or less skilfully, in the promotion of the improvement of the heat-engine in this direction.

The experiment of the French inventor, Du Trembley, was the first on a commercial scale and with apparatus constructed by expert builders. This attempt to utilize the principle here discussed was made in a number of steamships on an established ocean route, and on a scale which was entirely satisfactory, so far as the comparison of the older and the newer form of heat-engine was concerned. Its outcome was unfavorable, not from any defect in the plans of the inventor, but solely from the fact that the secondary fluid chosen was readily combustible and, at that time, at least, difficult if not impossible to confine permanently, completely and safely within the vessels in which it was expected to be utilized. To-day, the fluid would be no less dangerous if free; but the probability of it finding its way outside the engine by leakage would be greatly lessened by the better workmanship of our time. Such a fluid is, however, particularly objectionable on shipboard.

The French Government appointed a commission to investigate and to report upon the work of Du Trembley, and they studied the action of his binary-vapor machine as operating at the time in the steamer "Du Trembley;" the designs being those of Du Trembley, the steamship line that of Messrs. Arnaud & Touache, of Marseilles; the installation and operation being under the supervision of Mr. Jamieson, the superintending engineer.

The report of the commission stated that the engines of the ship were rated at 70 horse-power, arranged to be used together or separately. In the words of the report: "Sulphuric ether, requiring but a feeble heat to volatilize it, it seemed to him" (the inventor) "fitted to realize his ideas. He made the experiment and the result fulfilled his hopes. As soon as the vapor of water was in contact with the ether, it fell instantly to the liquid state and the ether evaporated. On the one hand, a new expansive force was created; on the other, a vacuum, which is also a force, was formed." Du

Trembley fitted his steam-engine with a surface-condenser, which served the double purpose of condenser for the steam and boiler for the liquid ether. The vapor thus produced was transferred into a secondary engine, constructed precisely alike the steam-engine in plan, and then was utilized by thermodynamic transformation to such extent as to add very considerably to the total power of the motive apparatus. The vapor rejected from the secondary cylinder was condensed in a surface condenser and returned to the vaporizer, whence it obtained its store of available energy at the commencement of its cycle. This constituted the "system of combined vapors of M. du Trembley."

The consumption of fuel with the engines using steam alone was reported by the commission as 4·31 to 5·51 kilos per horse-power hour, 9·5 to 9·9 pounds; and with the combined system, 1·11 to 1·16 kilos, 2·44 to 2·56 pounds.

The commission states that the cost of the ether is unimportant as affecting the ultimate economy of the system, and they assert that "the system of M. du Trembley presents a notable economy," and that, on the whole, it is a great advance. They consider the danger of ether very slight, being, as they say, "neither greater nor less than those of employing carburetted hydrogen-gas for illumination."

Several later ships were fitted with engines on this system. The "Jacquard" was found to suffer seriously — to be greatly endangered—by the escape of the combustible vapors of ether; and the engineers employed miners' safety-lamps in the engine-room. The secondary fluid was finally abandoned. The "Arago," fitted for a secondary system, was not so operated. The steamer, "La France," was burned at Bahia through the ignition of the ether, and the danger of approaching the tanks containing the supplies of that fluid was such as to prevent the efficient action of the fire department. The ship was destroyed. This misfortune closed that period of experiment with ether as a secondary fluid in binary engines.*

Sulphuric ether, employed by DuTrembley as the secon-

* See "Bourne's Treatise on the Steam-Engine," 1866, p. 393.

dary vapor in the binary engine, has this peculiar thermodynamic advantage over steam: that it superheats during adiabatic expansion instead of condensing. This, in the engine-cylinder, in the working engine, is a distinct advantage, as it tends to hold the fluid in the superheated, the gaseous, condition throughout the period of expansion and thus to restrict "cylinder condensation," initial condensation, of the working charge and that form of waste which is the most costly tax upon the steam-engine. Restricting heat-exchanges between the working fluid and the metal of the cylinder by this automatic action of superheating should therefore give such substances definite superiority over the fluids which, like steam, tend to condense with performance of work in the engine and thus to promote waste. It is doubtful, however, whether it will prove practicable to introduce such substances as rivals of steam, when, as in the case of naphtha and of ether, the fluid is readily combustible and explosive.

The experimental examination of the Du Trembley binary engines gave results which are, in essentials, the following:*

Initial pressures	Steam,	43·2 lbs.;		Ether,	31·2.
Back-pressures	"	7·6	"	"	5·3.
M.E.P.	"	11·6	"	"	7·1.

The steam supplied, thus, 62 per cent. of the total power; the ether, 38 per cent.; but the comparison between the steam-engine employed without the secondary and the latter as then utilizable by employing simply the water-heat of the primary, under the best conditions for the steam-engine, would have been more nearly steam 75 and ether 25, which latter figure is that giving the real accession of power due the secondary engine.

The consumption of fuel, as reported by Gouin, was between 2·4 and 2·8 pounds of good coal per horse-power hour, a figure which was soon improved upon by steam-engine builders without employing a secondary fluid.

Du Trembley built for the French steamer, "Brésil,"

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* Gouin's Report.

engines of considerable size and power, and again made a test on a large scale of the Steam-and-Ether Engine, about 1850. It was reported by M. Gouin that the consumption of fuel was as low as 2·44 pounds per horse-power hour, a decided improvement upon the steam-engine of the time. The compound marine steam-engine later introduced, and which is a fair standard of comparison, still further improved upon these figures. It was from these results that Rankin was led to a consideration of the problem of the series-engine and to declare that "the binary-vapor engine is not more economical than steam-engines designed with due regard to economy of fuel; but, by the addition of an ether-engine, a wasteful steam-engine may be converted into an economical binary-vapor engine."

A generation later, Messrs. Haswell, Goring and Torrance tested a binary engine in which carbon disulphide was the secondary fluid and obtained, as reported, the horse-power hour of 1·4 pounds of good coal. The trial was, however, too short, and the result too extraordinary for a small engine of less than 90 horse-power, to permit the acceptance of the reported figure without further investigation. In this engine, the rejected heat from steam of 15·3 pounds pressure was reported to produce a pressure in the secondary fluid of 76 pounds, by gage, substantially equal to that of the steam-boiler supplying the steam to the primary element of the combination. The trial was but five hours long and involved cleaning the fire. It must probably be admitted that the machine was very economical of fuel and steam.

Mr. Barrus, in 1887, reported the results of a trial of a new form of heat-engine in which the single fluid employed was ammonia, and the results were checked by operating the same engine with steam alternately with the ammonia. The outcome of the trial would seem to indicate the correctness of the surmise of the writer that wastes of heat by extra thermodynamic processes may be less with other fluids so used than with steam.

The data and results obtained by Mr. Barrus, by three tests of a Campbell ammonia-engine and boiler, as reported

to the Campbell Engine Company, April, 1887, were as follows:*

TABLE VI.—AMMONIA ENGINE.

DIMENSIONS OF BOILER AND ENGINE.

Boiler.—One horizontal-return tubular, set in brickwork.

Diameter of shell	42 in.
Length of shell	10 ft.
Inside diameter of tubes	1·75 in.
Area of water-heating surface	369·3 sq. ft.
Area of steam-heating surface	318·8 "
Area of grate-surface	9·17 "
Collective area for draught through 67 tubes	1·12 "
Ratio of water-heating surface to grate-surface	40·3 to 1
Ratio of steam-heating surface to grate-surface	33·6 to 1
Height of smoke-stack above grate	30 ft.

Engine.—Porter-Allen automatic cut-off, single cylinder.

Diameter of cylinder	11·5 in.
Stroke of piston	20 "

DATA AND RESULTS OF TESTS.

Date	1887, March 8,	March 9,	April 16.
Duration of test	hours 8	10	7.45
Percentage of ashes, etc.	per cent.	9·9	8·2
Coal per hour per sq. ft. of grate	pounds 19·09	15·27	16·07
Boiler-pressure above atmosphere	100	95·5	86·6
Temp. of feed-liquid entering boiler	deg. F.	167·6	167
Temp. of gases entering stack	"	390	394
Vacuum in feed-well	inches	11·5	11
Revolutions of engine per minute	revolu. 205·2	204·5	201·5
Indicated horse-power developed by engine	H. P. 61·80	57·53	54
Proportion of stroke completed at cut-off		·189	·211
Proportion of stroke completed at release		·773	·791
Proportion of return stroke uncompleted at compression		·307	·342
Coal consumed per indicated horse-power per hour	pounds 2·832	2·433	2·729

The report upon the performance of the carbon-disulphide engine above referred to gives in detail the following facts and data:†

* "Manual of the Steam-Engine," Vol. I, p. 702.

† "Manual of the Steam Engine," Vol. I, p. 701.

The engine was of the Corliss type, jacketed, 16 inches in diameter of piston and of 4-feet stroke. The power was absorbed during the trials by a prony brake. It could thus be operated by either steam or other fluids. The boiler was the usual form of tubular, with plain cylindrical shell. Its heating surface measured 1,028 square feet; its grate, 21·6. The fuel was a bad quality of anthracite. Natural draught was employed.

The boiler produced steam which, in the operation of the system, circulated from the boiler through a vaporizer constructed like a surface-condenser, and thence flowed back to the boiler as hot feed-water. The vapor of CS_2 thus generated passed on to the engine as required, and on through its cycle, including a surface-condenser, where it was condensed and whence the liquid was pumped back into the generator or vaporizer. Both steam and CS_2 thus continuously, during the operation of the system, flowed in closed cycles and no loss of either fluid occurred if all worked properly.

The supply pipe and the cylinder were both jacketed with steam at boiler pressure. No leakage was discovered, either of the CS_2 or of the H_2O.

The period of reported trial was seven hours.

During the earlier steam-tests, the engine, without the secondary element, was reported to have used 4 pounds of anthracite coal per horse-power hour.

The following are tabulated data of the trial with CS_2:

TABLE VII.—CS_2 ENGINES.

ELEMENTS OF OPERATION AND RESULTS.

Date of trial	January 16, 1894.
Barometer	29·17
Temperature of external air	51·° F.
Pressure of steam at boiler	78·73 lbs.
" " " " generator	75·16 "
" " " " shell	22·46 "
" " " " in steam-jackets	70· "
" " CS_2 at generator	95·8 "
" " " " steam-chest	93·96 "
Vacuum in condenser	10·47 "
Feed-water used	13352 "
" " " per hour	1907·5 "

Temperature of CS_2 vapor at generator	258·5° F.
" " " " " steam-chest	289·1° "
" " " " " exhaust	92·3° "
" " engine-room	66·° "
" " feed-water	249·5° "
" " water of condensation	34·° "
" " water leaving condenser	84·° "
Mean pressure of CS_2, from cards	30·55 lbs.
Mean revolutions per minute	81·53
Mean indicated horse-power	104·77
Horse-power as shown by brake	93·3
Total fuel consumed	1829 lbs.
Coal per hour, per square foot of grate	12·15 "
Ashes	446· "
Percentage of ashes	24·4
Coal per hour	261·3 "
Combustible per hour	197·6 "
Water evaporated per I.H.P. per hour	18·21 "
" " from temperature of feed, per lb. of coal	7·3 "
" " " " " " " " " combustible	9·83 "
Equivalent evaporation from and at 212° per lb. of coal	7·274 "
" " " " " " " " " combustible	9·65 "
Fuel consumed per I.H.P. per hour	2·49 "
Combustible, per I.H.P. per hour	1·866 "

In the Campbell engine, of 1887, where *aqua ammonia* was used, and the constructor, as the conclusion from his experience, asserted a saving of about one-half by the simple substitution of this fluid for steam, the first cost of the engine was stated to be no greater for ammonia than for steam.* The engine employed in these trials was, in fact, a Porter-Allen engine, built from the regular patterns used for steam-engines. The boiler was of the usual cylindric tubular kind. It was claimed, also, that the boiler was free from liability to either scale or corrosion when the proposed alkaline fluid was employed. The inventor of this apparatus claimed for the fluid these advantages: "Absorptive and radiating power; non-inflammability; non-corrosive action; non-incrusting effects; non requirement of cylinder lubrication; absence of foaming at the boiler; dry vapor even at exhaust; simplicity of apparatus and ease of man-

* "Results of Tests." New York, 1887. Pamphlet issued by the Campbell Engine Company.

agement." The experts reporting upon the trials of the engine conclude that one-third less heat, steam and fuel was required by the engine when using ammonia than as a steam-engine—condensation being adopted in both cases.

No difficulty appears to have arisen in the operation of the "plant," and leakage did not occur to any appreciable extent; only a slight odor of ammonia being observable about the stuffing-boxes. The apparatus was in operation for several months in New York City. Other conclusions of the experts were: The apparatus may be easily arranged by utilization of any condensing steam plant, surface condensation being required, however, and the replacement of all brass parts in contact with the working fluid by iron or steel; joints are easily made with rubber gaskets; boiler-risks are reduced rather than increased by the substitution of aqua ammonia for water therein. These results were obtained by three independent investigators.

It was reported that the machine, employed as a steam-engine, demanded considerably more fuel than when used as an ammonia-engine, when the figure was about 2·4 as a minimum when delivering about 60 horse-power, the duration of the test being ten hours. Another inventor, Mr. Ellis, supplemented the steam-engine by an ammonia-engine and obtained very similar figures. Other attempts in this direction have given good results.

A multiple-vapor series-engine was proposed by Wellington, who, having spent a large amount of time and money in preliminary work, died without having reduced his invention to practice and without having determined its value or even its promise. He proposed to employ a vapor-series, like, for example, the petroleums of varying densities, selected to suit the purpose, worked in a corresponding series of cylinders, *en cascade*, as it is termed by the French. His plan has never been fully developed or tested.*

"Cylinder condensation" obviously affects the multiple-cylinder engine—other things equal—less than the simple,

* "Manual of the Steam-Engine," p. 700.

whether the machine be also a multiple-vapor or multiple-fluid engine or no; and if the secondary fluid is less liable to this method of waste than its primary—the steam, the gas or the air-engine—the two gains conspire to reduce the wastes of the heat-engine taken as a whole. There is some evidence that those secondary fluids which have usually been adopted, in such multiple-fluid engines as have been hitherto experimented with, are less liable to this form of waste, exhibiting sometimes much less tendency to heat-transfer between working substance and cylinder wall than steam. But it is probable that much more work must be performed in this field of research before we shall secure satisfactorily definite knowledge on this subject.

Light petroleum has been employed as a working fluid in heat-engines; and while the experiment has been on too small a scale to permit a definite judgment regarding the value of the fluid for its purpose and while the properties of the substance which affect its thermodynamic value have not been yet ascertained, there is some evidence that it may prove, on the whole, a more efficient working fluid than steam, and to possess other advantages, consequent upon its physical nature, which give it standing in this field. But it is exceedingly inflammable, liable to remarkably violent and dangerous explosions, and thus particularly objectionable where, as on shipboard, it must be stored in considerable quantities under circumstances favorable to destructive results in case of becoming accidentally fired. As a fuel, it is rich in thermal energy, compact, readily stored and very easily and cheaply manipulated; as a working substance in the engine, it probably will be found to possess the special advantage of limited "cylinder condensation" and of performing the part of a lubricant on the piston and rod.

The light petroleums have no fixed boiling-points, as they are composed of a variety of definite compounds having a similar variety of physical properties and boiling at different pressures and temperatures. In vaporization, they boil in the order of their volatility, and the pressures which correspond to their boiling points, usually high in

comparison with steam, follow a similar order. Thermodynamically, they have, in many cases, excellent qualities for the series heat-engine.

Where they have been used, as in the experimental work of Mr. Yarrow, it has been found that a comparatively small area of boiler-heating surface is required for a stated efficiency of vaporization and the whole apparatus may be made exceedingly compact.

Mr. A. F. Yarrow's work with petroleum engines was sufficiently extensive and fruitful to at least give those fluids peculiar interest, considered as working substances in engines.* His investigation had its origin in the observation of experiments previously carried on in the United States with petroleum engines in small launches or yachts. The first comparison of work obtained with steam and with petroleum spirit, used alternately in the same engines, resulted in the conclusion that, with equal expenditure of heat, the petroleum engine supplied about twice as much power as the same machine operated by steam. The following are the figures reported:

Quantities.	Steam.	Spirit.
Cubic feet gas-fuel per hour	82·20	83·48
Gage-pressure	37·99	55·80
Revolutions per minute	312·60	552·20
Brake-tension	1,154	1,322
Foot-pounds per minute	2,524	4,722
Indicated work	5,199	11,975

The figures are thus nearly two to one in favor of the spirit. Also, the measurement of the indicator diagrams gave similar results to those obtained by brake; the work of the steam-engine being found to be 5,199 foot-pounds per minute; that of the petroleum engine being 11,975. The "spirit" used had a density of 0·680, water being taken as unity. Gasolene, equally available, has a density of 0·650, benzine of 0·725 and refined petroleum approximating 0·800. The light petroleums all have one common and serious objection—their inflammability—which, combined

* "Proceedings Brit. Soc. Arts," May 22, 1889. *The Engineer*, London May 31, 1889, p. 470.

with their volatility and vicious explosiveness, makes them peculiarly dangerous wherever inclosed in such manner that their vapors, when leakage occurs, cannot be freely swept away by currents of air.

Mr. Yarrow built many small launches with petroleum engines and with great success, from the builders' and the engineers' points of view. They could, when 36 feet in length, attain a speed of 8 miles an hour and carry fuel for 200 miles. They could be started in five minutes from the instant of lighting the fires. The machinery was very light and the fuel, also petroleum, was the most concentrated possible form of stored heat-energy. Experience showed it to be possible to make the waste-heat exceedingly small in amount, the hand being, as the builder reported, held over the chimney when in action without inconvenience, in the case of the so-called "Zephyr" launches thus constructed.

Later experiments with launch engines were reported by the same constructors, in which a similar comparison was made by using the engines alternately as steam and as petroleum engines.* The same general results were obtained and the petroleum engine produced double the amount of power given out to the brake by the steam-engine with equal quantities of heat and fuel. The brake showed a ratio in favor of petroleum of 1·878; the indicator, also, exhibited a ratio of 2·303. The operation of the boats supplied with such engines confirmed the deductions from the brake trials.

[*To be continued.*]

LIQUID FUEL FOR STEAMERS.

According to recent English exchanges the Red Star liner "Kensington" has been ordered to the Tyne, where she will be fitted with patent oil-burning furnaces by the Wallsend Slipway and Engineering Company, Limited. Whereas the previous vessels converted into oil-burners by this company have been tank steamers, the "Kensington" is a large Atlantic trader, and will be the first vessel of her type that the Wallsend firm has adapted to oil-burning.

* *London Engineering*, June 22, 1888, p. 609.

A New Device for Stereoscopic Photomicrography.

By Frederic E. Ives.

I have recently made a one-plate-one-exposure stereoscopic photomicrographic camera which is interchangeable with the single camera on the adjustable base described in the *Journal of the Franklin Institute* for May, p. 375. It consists of a light telescopic box camera for plates $3\frac{1}{8}$ x 6 inches, which is provided at the front with a small prism box containing three equilateral prisms, so disposed as to divide the light at the eyepoint above the eyepiece of the microscope, and project the divided rays upward to form the two stereoscopic images. *Fig. 1* shows the parts drawn to scale. *A* is the camera, *B B B'* are the prisms, *C* is the microscope tube with objective and low-power eyepiece, *D* is the object slide, and the dotted lines show the path of the axial rays from the back of the objective.

It is the usual practice to divide the light at the back of the objective, but inasmuch as the spot of light at the eyepoint, above the eyepiece, is an image of the back of the objective, it answers the same purpose, when working with an eyepiece, to divide the light at this point; and in the present device this is accomplished by the small equilateral prism. If this prism is perfectly accurate, the result is two images as perfectly stereoscopic and as perfectly defined and evenly illuminated as the images projected one at a time in the usual way; in fact, the images may be more evenly illuminated than is possible in the usual way when the objectives have long mounts.

By adding a lens of the focal length of the camera, for which there is room by using it as a cap for the eyepiece, the camera can be used without even refocussing, in the manner described in my communication already referred to.

The prism box has a lateral fine adjustment by screw on the camera front, in order to readily set it so that the apex of the small prism exactly bisects the circle of light at the

eyepoint. This adjustment can be made by looking through the prisms from the back of the camera.

I think it is a mistake to divide the light anywhere back of the objective when working with high powers on transparent objects, because some of the diffraction pencils, which define very minute details, emerge from the half of the objective opposite to that which belongs to the respective dioptric projection. It is probably for this reason that the Wenham

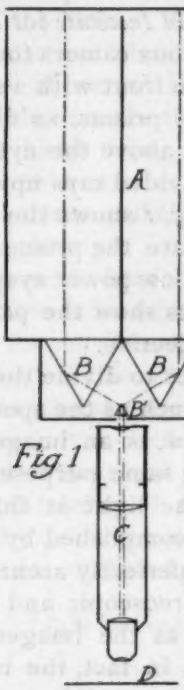

Fig 1

binocular cannot be made to perform satisfactorily with high powers. This stereoscopic camera, for precisely the same reason, should only be used for subjects which may be satisfactorily shown in the binocular microscope. With a 2-inch huyghenian eyepiece, amplifications from x10 (3-inch objective and short tube and camera) to x120 ($\frac{1}{3}$-inch objective and long tube and camera) can be made satisfactorily by employing color-sensitive plates and a yellow screen.

With Zeiss' 16-millimeter apochromatic objective and the "finder" (2) compensation eyepiece, ordinary plates can be used without the color screen.

The negatives produced in this camera are ready for printing from, no transposition of images being necessary, and for this reason only I prefer it to two otherwise equally simple and efficient combinations with which I have worked.

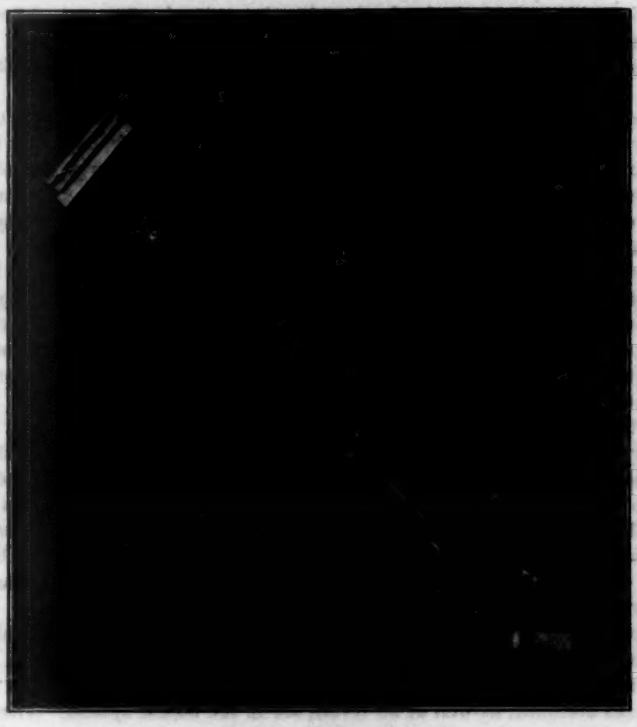

FIG. 2.

Fig. 2 shows the stereoscopic camera used on my adjustable base, as recently improved. This combination can be adapted to the microscope at any inclination and brought into action in a few seconds; and, after exposing, it is removed as a rigid whole by a single rectilinear movement of one hand.

Correspondence.

THE METRIC SYSTEM.

TO THE SECRETARY:—I have been greatly interested in the various expressions of opinion relative to the introduction of the metric system, and have been hoping to see something from some one resident in our sister Republic of Mexico, where for some six or seven years the metric system has been compulsory. One of our most influential New York journals, an ardent advocate of the metric system, is fond of saying, by way of argument, "Look at Mexico." That no one has spoken from Mexico is, possibly, because those engineers who are here find so little friction that the matter hardly attracts notice.

I came to Mexico about five years ago, on a twenty-four hours' notice, to take charge of one of the largest smelting plants in the country, and had barely time to reach the works before the date when the man in charge was obliged to leave, and for that reason had no time to look forward with apprehension to the difficulties which I would probably encounter with the metric system. Of course, it occurred to me that all weights and assays of ores from which the furnace charges were to be figured were in the metric system. But in this there was little difference, for, except the assays of silver and gold, the factors were all in per cents. We spoke of tons, but we meant metric tons. Arithmetically all routine was certainly easier, but not greatly so, except in obtaining metric tons from kilos, as compared with obtaining American tons from pounds.

As the works had been planned some five or six years previously, it was not surprising that all the plans were made in feet and inches, and that in construction and repair work we continued to use the same measurements. And so for four years I gave little thought to the metric system. I was probably like many of us Philadelphians, of partly Quaker origin, who use with equal facility the "plain" and "plural" languages, as the case may be. If it was ore purchased and assayed it was the metric system; if it was construction or repairs, it was feet and inches.

About a year ago I was sent by the company to the State of Chihuahua to superintend some new metallurgical operations, and it is surprising to me at this time to see the Babel of standards. The survey of the land upon which the works are built, as well as all levels, are in the metric system. The plans for all buildings and machinery are in the American system. A building so many feet long and so many feet wide is on such and such a meter level. All lumber ordered from Texas or from the mills in the Sierra Madre is ordered so many inches by so many feet in customary United States sizes. Local dealers sell you so many meters of such or such inch pipe, and the bill so reads. All valves and fittings come in inches. Of merchant iron you buy so many kilos of the dimensions given in inches, and I have a list card from one of the Mexican manufacturers of bar and sheet-iron giving the dimensions in ½, ¼, ⅛ and $\frac{1}{16}$ of an inch, that would suit the most conservative of your correspondents. Obliging salesmen in the stores can always give you the

price in "metros" or "varas." Your cordwood has to be converted from "cargas" and your hay or straw from "arrobas." So completely, however, has the metric system come into use in the purchase of ore that only in very remote regions does one still hear of the "marco." It must be observed, however, that in all bills which are to act in the nature of receipts for settlement, the controling factor of either weight or length must be in the metric system.

I believe that the United States should do all possible to advance the metric system, but from my experience in this most autocratic of republics, I do not believe, that should they make a compulsory law, either the advantages or apprehended difficulties would so immediately become apparent.

Yours truly,

R. C. CANBY,

MONTEZUMA LEAD COMPANY,
SANTA BARBARA, CHIHUAHUA, MEXICO,
September 12, 1902.

Book Notices.

Sur les Principes de la Mécanique Rationnelle. Par C. de Freycinet, de l'Institut. Un volume in-8 de viii-170 pages. Paris: Gauthier-Villars, 1902. (Price, 4 frs.)

The author discusses in Chapter I the concepts of mechanics—space, time, the relation of space and time or velocity, the definition of motion, force, mass, quantity of action, work, mass-motion, energy, center of mass or of gravity. Chapter II treats of the general laws of motion—the law of equality between action and reaction, law of inertia, law of the independence of action of forces, law of the mechanical equivalence of heat, remarks on statistics. In Chapter III the dynamic problem is treated. W.

Die Elektrolyse des Wassers: Ihre Durchführung und Anwendung. Von Victor Engelhardt (Mit 90 Figuren und 15 Tabellen im Text). Halle a/S. Verlag von Wilhelm Knapp. 1902. (Preis M. 5.)

The above entitled work constitutes the first of a series of "Monographien über angewandte Elektrochemie," which are to appear from time to time from the press of this publishing house. The announcement of this undertaking, with which the names of a large number of experts actually engaged in the electrochemical industries, should be of special interest to American manufacturers, engineers and inventors in this rapidly developing branch of applied science.

The present treatise on the electrolysis of water is made the first of the series, and very properly, since the phenomenon of the electric dissociation of water, both from the historical and scientific point of view, is a phenomenon of fundamental importance.

The subject is treated as follows: (1) Historical review, (2) the constants of electrolytic water dissociation, (3) review of various methods of procedure, (*a*) methods and apparatus for the separate production of oxygen and hydrogen; (*b*) for electrolysis without separation of the gases, and (*c*) the electrolytic production of oxygen only; (4) applications, and (5) supplementary tabular data.

The work of the author appears to have been very thoroughly done.

The book is well printed and the illustrations are numerous and well executed. W.

Die Normal Elemente und ihre Anwendung in der Elektrischen Messtechnik. Von Dr. W. Jaeger, Kaiserl. Professor, etc. Halle a/S. Verlag von Wilhelm Knapp, 1902.

This work treats in a very thorough manner of the voltaic cell, in theory and practice. W.

A Travers la Matière et l' Énergie: par le Dr. F. E. Blaise, Ancien Interne des Asiles d'Aliénés de la Seine, etc. Un volume grand in-8°, 68 photogravures dans le texte. Paris: Librairie Ch. Delagrave. (Prix, broché, 12 frs.)

This volume treats, in its first part, of electrochemistry and mechanics; in the second, of matter; in the third, of the formation of bodies and their luminosity; in the fourth, of electricity; in the fifth, of electric induction, and in the sixth and last, of certain conclusions drawn from the foregoing, and of certain philosophical considerations. W.

Publications Received.

Renold High-Speed Silent Driving Chain: The Link-Belt Engineering Company.

Power Plants of the Pacific Coast. (Report from *Trans.* N. Y. Electrical Society). F. A. C. Perrine, D.Sc. From the author.

Normal Construction: "Triebwerke" (Driving-Gears) section 7. W. H. Uhland, Leipzig, Germany. From the author.

The Alasko-Canadian Frontier. Thos. Willing Balch (8vo. pp. 45, with plates). Reprint from the *Journal Franklin Institute.* From the author.

Franklin Institute.

[*Proceedings of the Stated Meeting held Wednesday, October 15, 1902.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 15, 1902.

Vice-President WASHINGTON JONES in the chair.

Present, 240 members and visitors.

Additions to membership since last meeting, 6.

Mr. Edwin S. Balch was elected as a member of the Board of Managers in place of Mr. Benj. Smith Lyman, resigned.

Mr. Cyrus Chambers, Jr., made an interesting address on the art of bread-making, with especial bearing on the so-called "Scientific Bread-Machine," invented by Mrs. Lydia C. Sharpless. The speaker's remarks were profusely illustrated by means of lantern photographs, by the exhibition of the specimen machines, and by an experimental demonstration of the operation of the machine.

The subject was referred to the Committee on Science and the Arts for further consideration.

Adjourned.

WM. H. WAHL, *Secretary.*

Committee on Science and the Arts.

(*Abstract of proceedings of the stated meeting held Monday, October 1, 1902.*)

MR. THOS. P. CONARD in the chair.

The following reports were adopted:

(No. 2174.) *Cipher-Code System.*—Willis J. Roussell, New Orleans, La.

ABSTRACT.—This invention is the subject of letters-patent of the United States to applicant, No. 642,721, February 6, 1900, and relates to improvements in the arrangement of a cipher-code index by which the composition of or translation of a cipher message is made more easy and with less liability to error. (A brief statement of the system is impracticable). The conclusion of the sub-committee is that "the improvements devised by applicant for a more perfect method of securing absolute secrecy in cipher messages, and in producing a system of more general application than any which has preceded it, are worthy of recognition." The award of the Edward Longstreth Medal of Merit is made to the inventor. [*Sub-Committee.*—E. A. Scott, Addison B. Burk.]

(No. 2186.) *Tangential Water-Wheel.*—Wm. A. Doble, San Francisco, Cal.

The improvements of Mr. Doble are covered by letters-patent of the United States, Nos. 619,158–9, 633,184, 659,794 and 660,789. These relate in part to an improved form of bucket, and in part to an improved regulating nozzle,

neither of which are susceptible of intelligible description without illustrations. The award of the John Scott Legacy Premium and Medal is recommended. [*Sub-Committee.*—A. M. Greene, Jr., Chairman; Edw. T. Child, L. D'Auria, John E. Codman.]

(No. 2211.) *Siphon Condenser.*—Arthur Pennell, Kansas City, Mo.

ABSTRACT.—The invention consists of a T-shaped steam and water connection, with which the exhaust and circulating water-pipes connect, a condensing chamber in which is placed a spraying device or "water-breaker," and a vertical draft tube through which the gases and circulating water are discharged. The condensing chamber is attached below the T-shaped connection and the draft tube (36 feet long) connects with the bottom of the condensing chamber. The "water-breaker" is supported centrally in the condensing chamber by a stool, the legs of which rest on the flanges into which the draft tube is secured. The circulating water enters through a pipe attached to the top of the T-shaped connection, and the exhaust steam at the side. The column of circulating water, in falling on the cone-shaped water-breaker, is broken into a spray, thus presenting a large condensing surface for the condensation of steam. The air and other gases in the exhaust steam are enmeshed by the turbulent circulating water in the condensing chamber, and are carried downward by the falling column of water in the draft-pipe and discharged into the atmosphere at the bottom of the pipe.

The committee fails to recognize anything particularly new or of special merit in the invention. [*Sub-Committee.*—J. J. DeKinder, Chairman; John E. Codman.]

(No. 2221.) *Electric Elevator for Private Residences,*—Otis Elevator Company, New York.

This report is reserved for publication in full. The John Scott Legacy Premium and Medal is recommended to the inventors. [*Sub-Committee.*—T. Carpenter Smith, Chairman; J. Logan Fitts, C. C. Heyl, Francis Head.]

(No. 2227.) *Electro-Magnetic Geological Balance.*—Estrado, City of Mexico, Mex.

(An advisory report.)

(No. 2231.) *Screw-Cutting Engine Lathe.*—Otto E. Evans.

ABSTRACT.—The designer dispenses with the step-pulley, the variable speed of the spindle being obtained by gearing, the combination of which can readily be changed. The carriage is secured to the front face of the bed, reaching over less than one-half of the upper face. The middle and rear part of the upper face of the bed forms the bed for the tail-stock. The cross-feed of the carriage is positively geared. The cross-slide is moved by a comparatively large but short wormlike screw gearing into a rack. The taper device is attached to the front face of the bed and accomplishes the respective cross movement by means of a rack gearing into a spur wheel secured to the screw shaft. The change in the speed of the bed-screw is accomplished by gear wheels, the combination of which is governed by handles.

The report proceeds to enumerate the comparative advantages and disadvantages of this design, and concludes that the disadvantages far outweigh the possible advantages obtained by the new design. [*Sub-Committee.*—Hugo Bilgram, Chairman; Arthur Falkenau.]

(No. 2233.) *Improved Grate.*—James Reagan, Philadelphia.

ABSTRACT.—A re-investigation to ascertain whether the inventor's claim that the grate would neither warp, welt, nor get out of position in service, was justified by experience.

The Investigating Committee made an extended canvass among the users of the Reagan grate with the view of confirming this claim. All the correspondents from whom advices were received subtantiated the claim without reservation. The committee recommends the award of the John Scott Legacy Medal and Premium. [*Sub-Committee.*—James Christie, Chairman; J. M. Emanuel, Robt. D. Kinney, Wilfred Lewis.]

(No. 2236.) *Improved Roll for Crushing and Grinding.*—Gerdt Gerdtzen. (An advisory report.)

(No. 2241.) *Compartment Drawer Bottom.*—John Gowdey, Philadelphia.

This device consists of a drawer bottom having a series of regularly spaced kerfs (¼ inch apart) cut into it, crossing one another at right angles over its entire surface. These kerfs are of sufficient width and depth to receive and support partitions of thin wood, cardboard, vulcanized fiber, etc., by which the drawer may be divided into any number of compartments of any desired size to accommodate all sorts of miscellaneous articles of varying size and shape.

The committee reports that the idea is a meritorious one and that the invention should prove useful in service. The Certificate of Merit is awarded. [*Sub-Committee.*—H. R. Heyl, Chairman.]

(No. 2244.) *Improved Door-Check.*—Eugene I. Blount and Warren H. Taylor.

ABSTRACT.—The object of these imprints is stated to be to enhance the efficiency of door-checks, simplify their construction, and reduce the cost of manufacture; also to provide means whereby the person attaching the device can see at a glance whether the spring is set for a right or left-hand door.

The report finds that the indicator device, and the arrangement of the device on which the spring winds so that it cannot be unwound, are improvements. The details of the apparatus also are thoroughly worked out. The Certificate of Merit is awarded. [*Sub-Committee.*—Ernest M. White, Chairman; L. L. Cheney, Geo. S. Culler.]

(No. 2245.) *System of Control for Electric Motors.*—H. Ward Leonard, Bronxville, N. Y.

This report is reserved for publication in full. The award of the John Scott Legacy Premium and Medal is recommended. [*Sub-Committee.*—Francis Head, Chairman; Arthur J. Rowland, L. F. Rondinella.]

The following reports passed final reading:

(No. 2173.) *The Philadelphia City Hall Tower Clock.*—Warren S. Johnson, Milwaukee, Wis.

(No. 2207.) *Models for Stereometric Representation.*—W. F. C. Morsell, Philadelphia.

(No. 2214.) *System of Gearing.*—Wm. L. Schellenbach, Cincinnati, O.

(No 2238.) *Improvements in Electric Illumination.*—Luther Stieringer, New York.

Sections.

PHYSICAL SECTION.—*Stated Meeting*, September 25th. Prof. George S. Stradling in the chair. Present, 22 members and visitors. Professor Stradling read a paper entitled "The Ionization of Gases." After some discussion of the subject, the meeting adjourned.

JESSE PAWLING, JR., *Secretary.*

CHEMICAL SECTION.—*Stated Meeting*, October 2d. Dr. William H. Wahl was called to the chair. Present, 18 members and visitors.

Dr. J. Merritt Matthews, Philadelphia Textile School, made an informal communication on "The Scientific and Industrial Development of Artificial Indigo," with an exhibition of specimens, and experimental demonstrations. The communication was referred to the Committee on Publication. Adjourned.

WM. H. WAHL, *Secretary, pro tem.*

ELECTRICAL SECTION.—*Stated Meeting*, October 9th. Mr. Thos. Spencer in the chair. Present, 70 members and visitors.

Mr. Joseph Sachs, of the Johns-Pratt Company, Hartford, Conn., read a paper on "Electric Fuse Protective Devices," which was illustrated by the exhibition of a large number of specimen fuses of this type, and by an instructive series of experimental demonstrations. Messrs. Carl Hering, C. J. Reed, Francis Head and others discussed the paper, which was referred for publication in the *Journal*. RICHARD L. BINDER, *Secretary.*

MECHANICAL AND ENGINEERING SECTION.—*Stated Meeting*, October 16th. Mr. James Christie, Chairman, *pro tem.* Present, 65 members and visitors.

The meeting was devoted to the discussion of the subject of "Multiple Voltage Systems for the Speed-Control of Tools." Messrs. James Christie, Charles Day, Francis Head and others participated.

DANIEL EPPELSHEIMER, JR., *Secretary.*

SECTION OF PHOTOGRAPHY AND MICROSCOPY.—*Stated Meeting*, held October 23d, 1902. Mr. Martin I. Wilbert in the chair. Present, 65 members and visitors.

Mr. Fred. E. Ives presented a communication describing an improved binocular microscope of his invention, and exhibited the apparatus.

The device consists of a simple attachment applicable to any short-tube microscope, by means of which it can readily be changed to a satisfactory binocular.

Mr. Ives also called attention to some improvements that he had made in his microscopic camera-box that is interchangeable with the camera on the stand. An interesting feature of this camera is the fact that the resulting prints do not need to be separated and reversed in the subsequent mounting, this being provided for in the prisms dividing the eye.

Mr. Ives then called attention to his "Parallax Stereogram," which was on exhibition.

Mr. W. W. Canby followed with an interesting series of lantern photographs taken during a recent trip through Alaska.

M. I. WILBERT, *Secretary.*